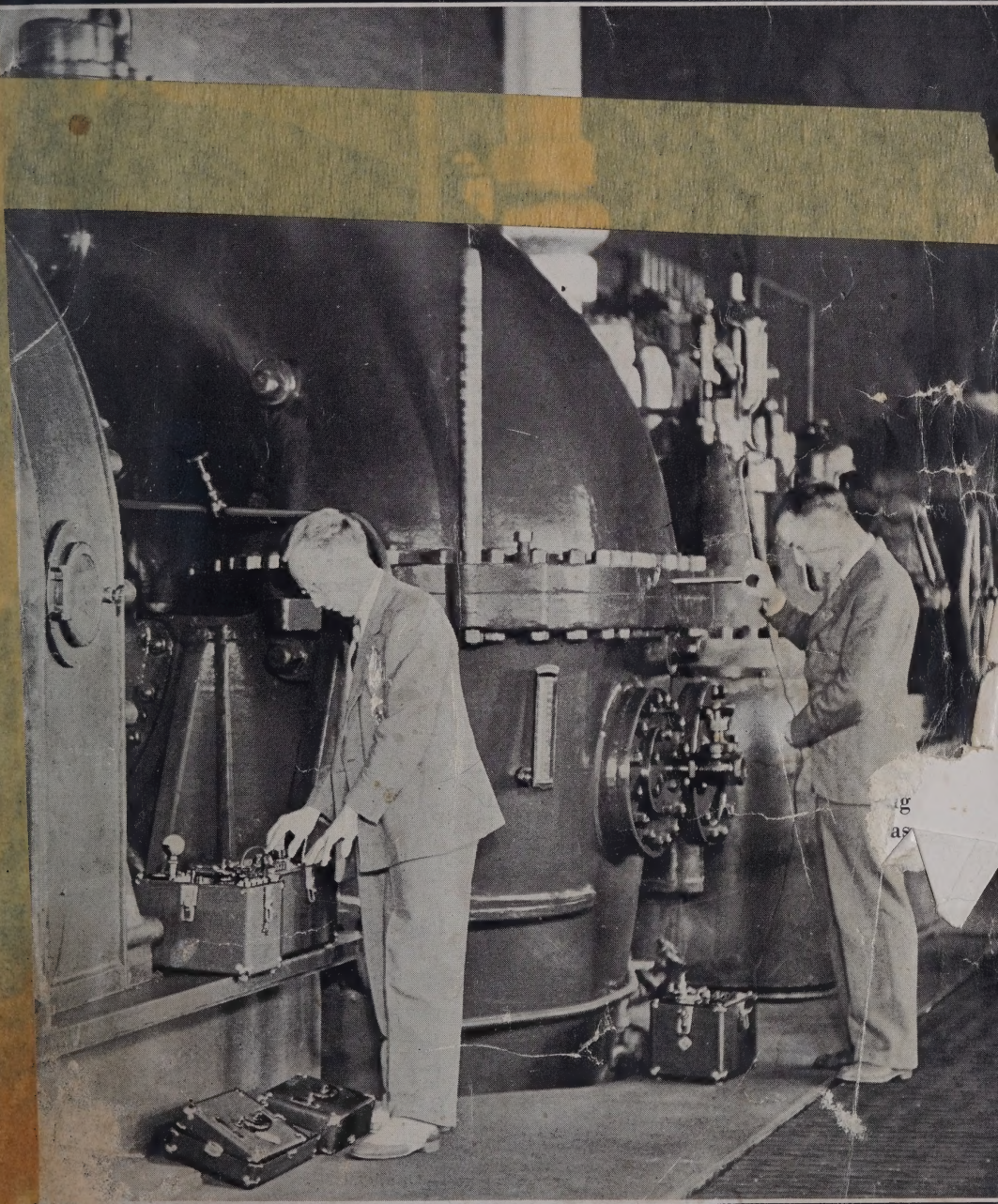
THE NOISE PRIMER



ENGINEERING DEPARTMENT

GENERAL RADIO COMPANY

CAMBRIDGE 39, MASSACHUSETTS, U. S. A.

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THE NOISE PRIMER

PART I—INTRODUCTION

Noise is currently the object of attack from several angles. Such organizations as the National Noise Abatement Council conduct a continuous campaign to make possible our existence in quieter surroundings, emphasizing the effects of noise on efficiency, health, and happiness. To such groups, the sound-level meter is the objective means of establishing the amount of noise and the degree of improvement.

Industry finds two serious effects of noise: First, too noisy a product meets marked sales resistance; and secondly, noise in a machine may be the result of poor construction or incorrect design. Vibration, always the generator of noise, is also recognized as an undesirable factor in machine performance. Its measurement has proved to be an important aid to design and testing.

There are also machines in which a high level of emitted sound from a vibrating surface is desirable. These include horns, sirens, alarm bells, loudspeakers, and similar signaling devices. Sound-level measurements are as important here as in noise reduction problems.

When noise measurements are necessary, one question to be decided is whether to purchase the necessary measuring equipment or to have the measurements made by a consulting laboratory. On problems of a temporary or unusually difficult character, the consulting service may be the best solution, but all measurements connected with the normal development or manufacture of a product are now generally carried out by the manufacturer's own engineering or production staff.

If, in the design, manufacture, or sale of your products you have regularly to measure or to analyze noise or vibration, you or others in your organization should be able to make the measurements quickly and accurately. For shorter jobs, you must balance the cost of the equipment (which is now surprisingly low) and the time against the possible consultant's fee. One important thing to remember is that, once the equipment is purchased, you have it, and it will also be very useful, perhaps invaluable, on future problems.

Do not, therefore, assume that your present problems are only temporary, or that you will never have any more like them. Do not deny your organization the advantages now of something you will probably need even more as time goes on.

General Radio noise and vibration measuring equipment is well-designed and simple to operate. To the manufacturer of equipment with moving parts, it offers an inexpensive and reliable solution to noise and vibration-measurement problems.

PART II—THE SOUND-LEVEL METER

Similarity to Ear

The sound-level meter or, as it is often called, the noise meter, is essentially a device for measuring the amplitude of rapid alternations in the air pressure. It does not measure the frequency, or pitch, at which such alternations take place. When these alternations occur within a certain range of frequencies they affect the ear and are known as "sound" or "noise." The sound-level meter is intended to provide a simple means of obtaining objective measurements which can be correlated with the response of the average ear.

The sound-level meter is not perfect in this respect. Not enough is now known about the ear to enable us to duplicate its response perfectly and, even if it were, the necessary equipment would be complicated, bulky, and expensive. Furthermore, for many engineering problems the conventionalized response of the sound-level meter is more useful than an exact ear response would be, since the ear response, by its complicated nature, is not subject to simple mathematical or physical analysis. As long as we realize its limitations the sound-level meter is a most useful device, and certainly the best thing for its purpose which has thus far been devised.

As an example of the many complicated characteristics of the ear, Figure 1 shows the familiar Fletcher-Munson curves, which are constant-loudness contours of the average ear for pure tones in terms of frequency and loudness level. These indicate that the frequency-response characteristics of the ear are not constant, but vary with the loudness of the sound. For instance, at low sound levels the ear is relatively insensitive to low frequencies, but at high sound levels it hears them almost as well as the higher frequencies.

The best known makes of sound-level meters are more or less alike. They are all intended to follow the standards

REFERENCES

[1]These curves are now incorporated in the American Standard for Noise Measurement, Bulletin Z24.2 — 1942, published by the American Standards Association, 29 West 39th Street, New York, N. Y. (price 25 cents). They were originally published in a paper by Harvey Fletcher and W. A. Munson of the Bell Telephone Laboratories entitled "Loudness, Its Definition, Measurement, and Calculation" and published in the Journal of the Acoustical Society of America, Vol. VI, No. 2, pp. 82–108, Oct., 1933. Curves of a similar nature, but based on earlier data, were published by B. A. Kingsbury, "A Direct Comparison of the Loudness of Pure Tones," Physical Review, Vol. XXIX, p. 588, 1927.

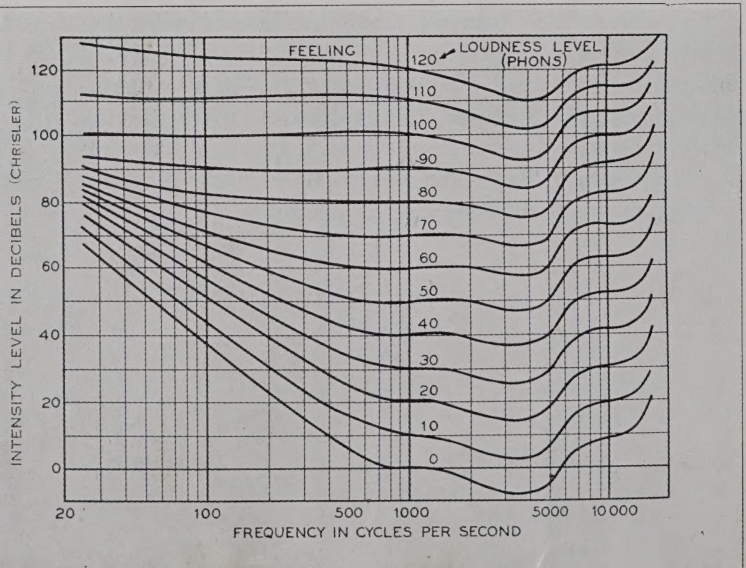


FIGURE 1. Equal-loudness contours for the average ear for pure tones. The reference level for intensity is 10^{-16} watts per square centimeter (0.0002 dynes per square centimeter).

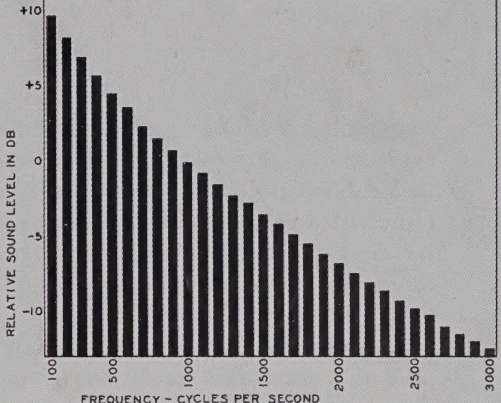


FIGURE 3. Chart of the relative contribution to total noise level made by 100-cycle bands over the frequency spectrum, as obtained from analyses of noises of a general character. (From A.S.A. Bulletin Z24.3 — 1944.)

specified by the American Standards Association,[2] and all leading manufacturers have now adopted similar mechanical and operating features. For most purposes they may be considered interchangeable, but in some few cases their readings will not be identical, although the meters may all meet the standards.

Microphone Limitations

A glance at Figure 2 will show one reason why this is so. The tolerances, which may seem excessively wide to those previously unacquainted with acoustical measurements, are made necessary by the limitations in available microphones. Most microphones were originally designed for use in the reproduction of music and speech and are not for purposes of quantitative measurement. There are many factors entering into the reproduction of speech and music (such as the ear, room acoustics, and the properties of the instruments and voice) that make it useless to maintain an absolutely flat or smooth frequency-amplitude characteristic in the microphone, particularly if it must be obtained at the expense of sensitivity or other desirable properties. Hence the frequency characteristics of standard microphone types vary considerably from a straight, flat line, particularly in the extreme upper and lower parts of the audible range. While, in many cases, the microphones used for sound measurement are improved in this respect over those

[2]American Tentative Standards for Sound-Level Meters for the Measurement of Noise and Other Sounds (A.S.A. Bulletin Z24.3 — 1944).

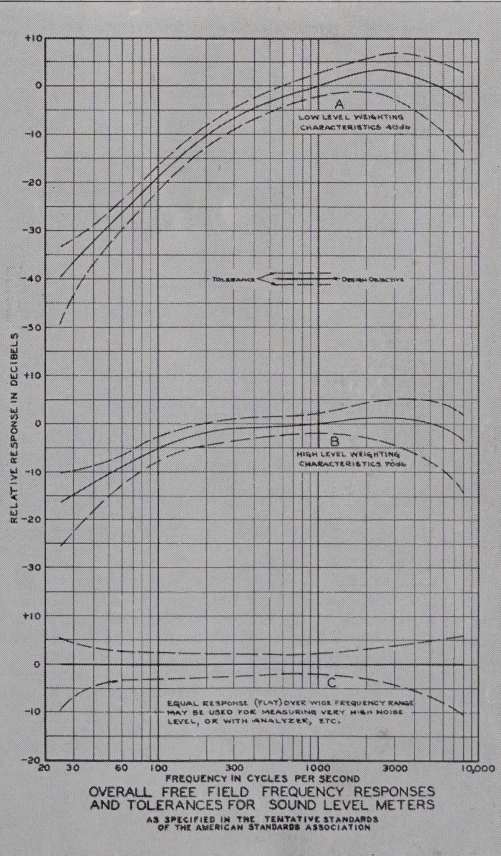


FIGURE 2. Design objective frequency-response curves between 60 and 8000 cycles for sound-level meters as specified by the American Standards Association (Bulletin Z24.3 — 1944).

OVERALL FREE FIELD FREQUENCY RESPONSES AND TOLERANCES FOR SOUND LEVEL METERS AS SPECIFIED IN THE TENTATIVE STANDARDS OF THE AMERICAN STANDARDS ASSOCIATION

commonly used for broadcasting and recording, the perfect microphone is yet to be developed, and present types all represent a compromise in order to get the best possible combination of good frequency response, stability, ruggedness, and sensitivity.

The tolerance curves of Figure 2 represent the maximum deviations from a given design objective to be expected with the best of present microphone types. So far as the electrical circuits in the sound-level meter are concerned, it is possible to make these follow any particular characteristic with a high degree of accuracy.

The microphone, then, is the poorest element in the sound-level meter, but the situation is actually much better than the tolerance curves would seem to indicate. The chart of Figure 3 shows the relative sound level in average noise for various frequency bands. It will be noted that the high frequencies become progressively less important, so that for most purposes components above 3000 cycles may be omitted altogether without serious error. Since a sound-level meter, in order to meet the standards, must have a certain amount of response up as far as 8000 cycles, it follows that, for sounds of general character, it will read quite accurately, providing it has a good low-frequency response.

Of course, there will always be some sounds with strong components above 3000 cycles or at very low frequencies, and it is on this type of sound that the greatest error will generally occur. The most serious discrepancies among different meter types generally happen when a strong component is at a frequency where one microphone has a valley in its response curve while the other has a peak. As an extreme, at 8000 cycles a possible difference of 15 decibels could result from this cause alone with meters meeting the standards in every way. In actual practice, however, differences even a fraction as large as this are uncommon, and occur only in exceptional cases. Also, for precise measurements, errors from this cause may be almost entirely eliminated through the use of an analyzer and a calibrated microphone, as will be described later.

A.S.A. Frequency Response Curves

Now that we know the worst that can occur, we can forget it for a while and go on to more practical and important aspects of the sound-level meter. It should be noted that the curves in Figure 2 bear an inverse relationship to those in Figure 1 and were actually derived therefrom. Since the A.S.A. committee realized that it was neither desirable nor practical to duplicate the ear response exactly, the curves for two representative levels (40 and 70 db) were taken from Figure 1, modified for random free-field response and smoothed.[3] The flat response (C) was added for use where measurements of actual physical sound pressures were desired and at very high sound levels, where the ear response is fairly constant.

In addition, the A.S.A. standards

[3]The curves in Figure 1 represent measurements made on one ear at a time (monaural) with a plane wave — that is, a wave striking the ear at a single given angle. The irregularities above 1000 cycles are due in large part to diffraction effects caused by the shape of the head or the outer ear. The curves in Figure 2 have been modified to duplicate as nearly as practical the response of the ear to sounds arriving equally from all directions. The smoothing allows the curves to be more easily duplicated by simple electrical circuits and is justified by the fact that binaural hearing eliminates many of the irregularities present in the curves of Figure 1.

(Z24.3) define various terms and units, specify other tolerances, and how the microphone is to be calibrated. Many of these points will be discussed in later pages. The standards are the result of some years' experience in the design, manufacture, and use of sound-level meters.

PART III—THE DECIBEL—WHAT IS IT?

In sound measurements the results are expressed in decibels. The higher the number of decibels, the louder the sound. A level of zero decibels represents roughly the weakest sound which can be heard by a person with very good hearing. In practical noise measurements anything below 24 decibels can generally be considered so nearly inaudible as to be of no importance. In fact, except in unusually quiet locations, noises below 40 decibels may generally be disregarded.

From the strictly technical standpoint, a given number of decibels represents a ratio, since the decibel is a logarithmic unit. In terms of sound pressure the formula is

$$\text{db} = 20 \log_{10} \frac{E_2}{E_1} \qquad (1)$$

where E_1 and E_2 represent the two sound pressures being compared.[4] This applies only under conditions where the power is strictly proportional to the square of the pressure, which is generally true for sound measurements in air.

In sound measurements decibels represent not merely ratios, but absolute levels, since a standard reference level has been agreed upon. This level is 0.0002 dynes per square centimeter at 1000 cycles.[5] This reference level is approximately 16 db below the average threshold of hearing.[6]

Do Not Add Decibels

Since the decibel is essentially a logarithm, addition of decibels produces multiplication of sound pressures. For instance, increasing any sound level by 6 decibels is equivalent to doubling the sound pressure. Do not try, therefore, to add two sound levels together by ordinary addition. Sounds of a general and complex nature add approximately as the relative sound power involved. That is, two sounds of equal power, when added together, produce twice the power, which is $\sqrt{2}$ times (not twice) the sound pressure.

The Equation (1) for decibels expressed in terms of sound pressure represents a special case which is valid only because, under conditions generally encountered, the air has a constant impedance. The more fundamental equation is expressed directly in terms of power and is

$$\text{db} = 10 \log_{10} \frac{P_2}{P_1} \qquad (2)$$

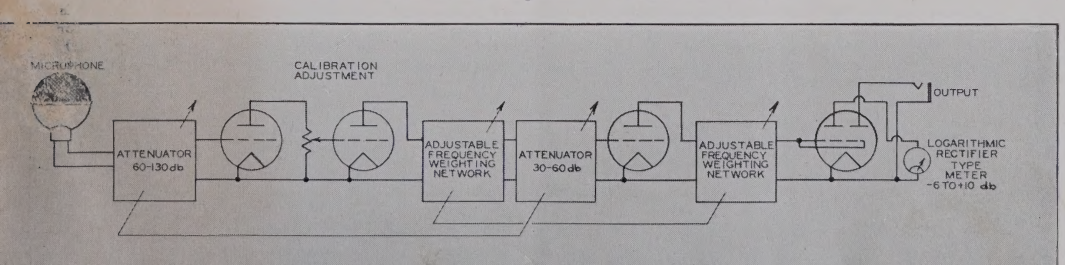
where P_1 and P_2 are the sound powers

[4] This is the same formula that is used in electrical communications to compare two voltages operating at the same impedance levels.

[5] Sound-level meter microphones respond to sound pressure. 0.0002 dynes per square centimeter is the practical equivalent of 10^{-16} watts per square centimeter, as specified in the American Standards Association Bulletin Z24.3—1944.

[6] See Steinberg, Montgomery, and Gardiner, "Results of the World's Fair Hearing Tests," Journal of the Acoustical Society of America, Vol. XII, No. 2, pages 291–301, October, 1940.

FIGURE 4. Functional diagram of a sound-level meter.



involved.[7] The standard zero reference level in terms of power is approximately 10^{-16} watts per square centimeter at 1000 cycles.

A slide rule, logarithm table, or, more conveniently, a decibel table (see page 38) is accordingly necessary for adding together sound levels expressed in decibels.

As an example, assume a sound of 50 decibels is to be added to one of 53 decibels. Looking in the decibel table, we find that the first represents a relative power ratio of 10^5, while the second represents a relative power ratio of 2×10^5. Adding these together, we get a total of 3×10^5, which is equivalent to 54.8 decibels.

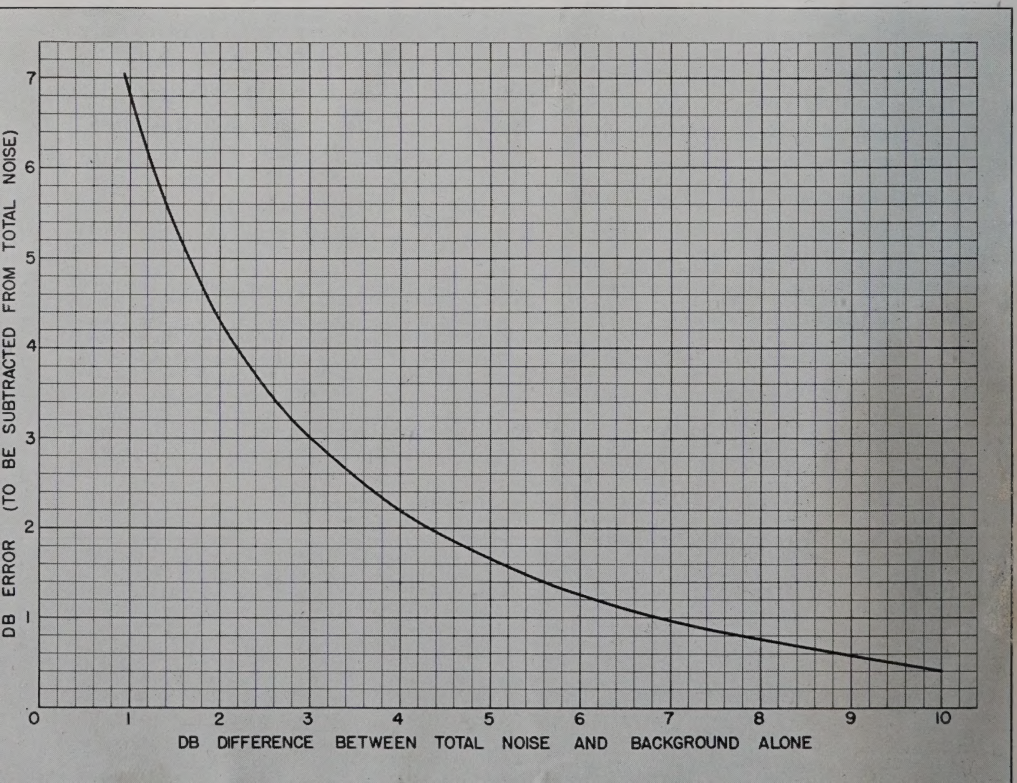
A simple relation to remember is that doubling the sound power is about equal to an increase of 3 decibels, so that when equal sound levels are added together, regardless of their actual value, the resulting level is 3 decibels higher than that of the originals. Thus, two sounds each having a level of 40 db would produce a level of 43 db when combined. If you add to a first sound a second which is 10 db lower in level (1/10 power) the resulting level is 0.4 db higher than the first sound alone, which is a negligible increase for most purposes.

[7] This is the exact equivalent of the electrical case, and the formula is the same as that which applies in general communications problems, where zero level is usually 1 milliwatt in a 600-ohm line.

Background Noise

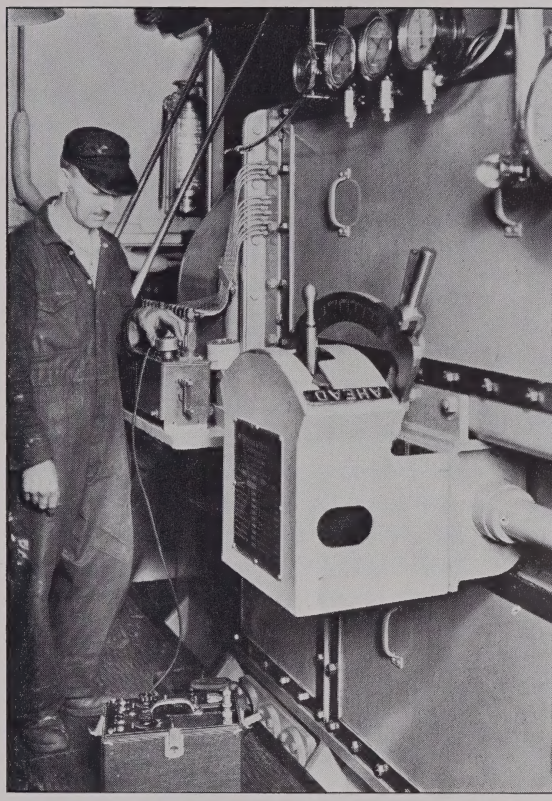
One of the most frequent applications involving the addition or subtraction of sound levels is the correction of readings for background noise. Ordinarily, of course, sound measurements should be made under conditions where the background noise level is negligible — that is,

FIGURE 5. Error introduced in sound measurements by background noise (from L. E. Packard, "Background Noise Corrections in the Measurement of Machine Noise," General Radio *Experimenter*, Vol. XII, pp. 6, 7, Dec., 1937).



at least 10 db below the level being measured. However, this is not always possible, and the curve shown in Figure 5 is convenient in those cases. The horizontal scale of this chart represents the difference in sound-meter reading with and without the machine under test in operation. The vertical scale represents the number of db to be subtracted from the total reading (machine plus background noise) to obtain the noise level generated by the machine alone.

The curve of Figure 5 can also be used to correct for any zero reading of the meter arising from vibration of the instrument or from internally generated electrical noise.



Loudness

It is generally assumed that the response of the ear to variations in sound intensity is logarithmic, but this is not strictly true. Figure 6 represents the actual relationship between the loudness as estimated by a large number of observers and loudness level. This curve shows loudness in L. U. (Loudness Units) plotted versus loudness level in phons.[8] Loudness level in phons for pure tones is equivalent for some purposes to sound level as measured by a sound-level meter, assuming that the meter has exactly the correct frequency response for the particular level being measured.

[8]A complete table of the function plotted in Figure 6 is given in the American Standards for Noise Measurement, A.S.A. Bulletin Z24.2—1942. This information is based upon the paper by Fletcher and Munson in the October, 1933, issue of the Journal of the Acoustical Society, referred to in Note 1.

In the strictest interpretation, loudness level in phons is measured by adjusting a 1000-cycle tone to exactly the same loudness as heard by the ear as the noise being measured, and then measuring the intensity of the 1000-cycle tone as with a sound-level meter. Loudness level and sound level correspond exactly, therefore, only for 1000-cycle tones.

As a practical matter, a sound-level meter, when the network corresponding most closely to the level being measured is used, provides readings closely approximating loudness level in phons for pure tones. Phons and loudness units are seldom used in machinery noise problems, but do have some application in physiological and psychological work.

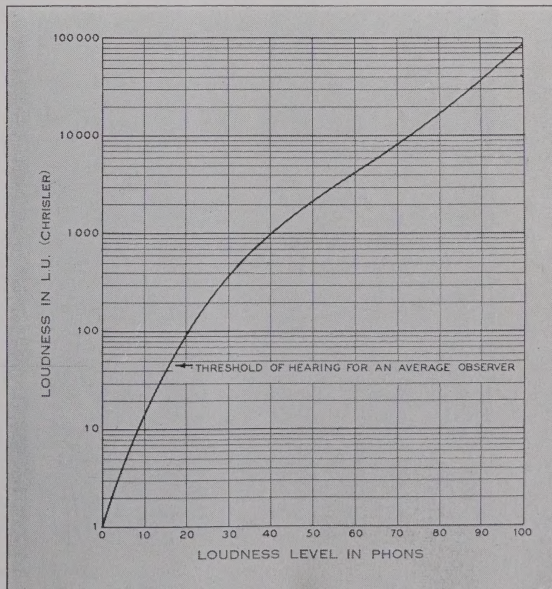


FIGURE 6. Relation between loudness and loudness level, from "American Standard for Noise Measurement," American Standards Association Bulletin Z24.2—1942.

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PART IV—HOW TO USE A SOUND-LEVEL METER

Operating Instructions

Manufacturers have tried to make sound-level meters as simple to operate as possible. The instruction sheets covering the actual mechanics of operating General Radio Company's TYPE 759-A and TYPE 759-B instruments are mounted in the covers. For those who may be unacquainted with the instruments, however, the following may be of interest.

A standard sound-level meter has, aside from various minor controls, three main controls and indicators which are used in taking the readings. The first of these is a knob generally marked WEIGHTING and providing choice of any of three frequency characteristics shown in Figure 2, page 3. The second is a knob generally marked DECIBELS, which shifts the sensitivity of the instrument in steps of 10 db. The third is an indicating meter calibrated over a range of approximately 16 db, which in effect interpolates between the readings of the decibels control. In operation the reading of the meter is added to that of the decibels control.

Other controls are generally provided for checking the calibration, changing the meter speed, etc.

Test Code

The American Institute of Electrical Engineers has formulated a test code covering certain standard methods of procedure particularly well adapted to the measurement of noises made by electrical machinery. The code is by no means complete and consequently does not apply in all cases, but it does form a basis for more specialized codes applying to individual applications.[9] In particular, it specifies standard test distances which can generally be followed in almost all cases. The standard test distances are 6 inches, 1 foot, and 3 feet. The distance should be measured between the nearest major surface of the machine under test and the microphone. When the microphone is mounted close to or on the sound-level meter

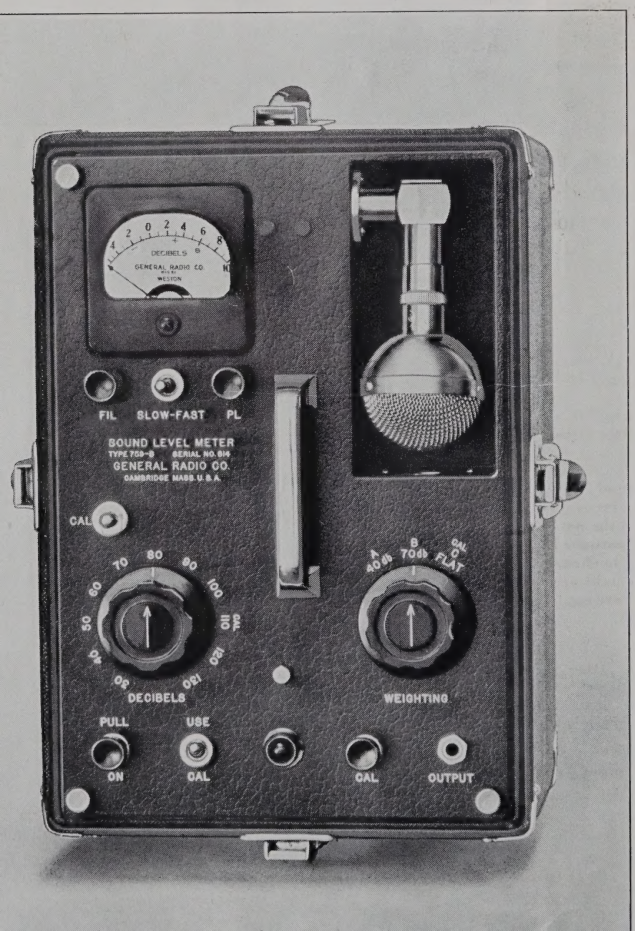


FIGURE 7. Panel View of the General Radio TYPE 759-B Sound-Level Meter.

[9] A.I.E.E. Test Code for Apparatus Noise Measurement, A.I.E.E. Bulletin No. 520, March, 1939, published by the American Institute of Electrical Engineers, 33 West 39th Street, New York, N. Y., price 30 cents. The test code is now being revised by the American Standards Association in collaboration with the A.I.E.E.

case, that end of the case should face the sound source.

Publication No. 44–95 of the National Electrical Manufacturers Association, entitled "NEMA Fan Standards," covers the standard test procedure for noise measurements on electric fans.

Microphone Placement

Remember that the sound-level meter measures sound pressure *at* the microphone, and that the sound pressure varies throughout a normal room and around a machine or other sound source. Microphone placement is probably the most important operation in the noise measurement procedure and about the only "trick" that has to be mastered by the beginner.

To measure with great accuracy the total noise output from a machine, it would be necessary to take an infinite number of measurements all around the machine and integrate the results. In actual practice measurements are made at equal intervals around a machine and at a fixed distance from it, the actual number of such measurements depending upon the complexity of the sound pattern and the importance of the results. Where extreme accuracy is not required, and particularly when the readings to be averaged are within a range of 10 decibels or so, a simple arithmetic average of the decibel readings is generally sufficient.

A more exact method involves converting the decibel readings to their corresponding relative power values, averaging these, and converting back to decibels. The procedure is similar to and involves the same principles as those previously described for the addition of sound levels, except that in this case the sum of the corresponding powers is divided by the number of readings to obtain an average, as shown in Table I, below.

This is the fairest way of comparing machines of different types or characteristics, but a simpler procedure can generally be used when comparing similar machines, as in production testing. A test position can be selected which gives a single reading that *varies* closely with the average noise as determined by the above method. This single test position is not necessarily one giving the *same* reading as the average. Usually it will be the position providing the *highest* reading.

This procedure may be modified in individual cases. For machines having a very pronounced noise pattern, two or more test positions providing fairly high readings might be used. On such machines, it is sometimes desirable, in order to get a better check on the total noise, to measure the level at these several maxima in the noise pattern and average the results, either arithmetically or ac-

TABLE I

Microphone Position	*Decibels Sound Level*	*Relative Sound Power (Antilog 1/10 Sound Level)*
I	50	100,000
II	55	316,200
III	60	1,000,000
IV	55	316,200
		4)1,732,400 total
		433,100 average

$10 \log_{10} 433{,}100 = 56.4$ decibels.

cording to relative power levels. This, of course, yields an average higher than the general average, and usually a more sensitive one. It provides a fair comparison only between similar machines. In comparing dissimilar machines, only a general average, taken with as many microphone positions as necessary, will be fair.

Choice of Weighting Curve

Aside from microphone placement, selection of the correct weighting curve is the next important factor in making noise measurements. Changing the weighting curve can produce variations in the results ranging from negligible differences in the medium and upper frequency range to variations of 20 or 30 decibels at low frequencies.

When all that is desired is knowledge of the sound level at the microphone, the problem is relatively simple. The following table shows the sound-level ranges and the weighting curve recommended:

Sound-Level Range	*Weighting Curve*
24- 55 db	A (40 db)
55- 85 db	B (70 db)
85-140 db	C (Equal response over entire range)

Strict use of this table will sometimes be impossible. For instance, a sound may read 54 decibels on the A characteristic and 56 decibels on the B, due to the greater weight given to low frequencies on the B curve. Similarly, although not so likely, a sound with a large amount of energy in the region of 2000 cycles might possibly read 56 db on the A curve and 54 db on the B. There is still, therefore, some judgment required in choosing the best curve to use under these conditions, but the following procedure is generally satisfactory. If the measurement is one of a series, most of which fall well within the range of a particular curve, this setting should be used for all measurements. If no such clear-cut distinction exists, it is desirable to record measurements made with both curves, noting, of course, the curve designation as well as the level. Where actual loudness is important, rather than mere changes in loudness or physical values, it is sometimes desirable to make measurements on both curves.

Always record the weighting curve designation as well as the decibel values.

Noise at Distance

It is not always the sound level at the microphone which is important, but rather the annoyance which the noise will produce at some distance. Under these conditions the choice of the weighting curve should be based upon the level at the point where the annoyance exists, although measurements may actually be made close to the machine as a matter of convenience.

For instance, assume that the problem is to quiet an airplane motor test chamber so that, with an engine running under test at full speed, neighbors some distance away will not be disturbed by the noise. Assume that at the neighbors' homes the sound has a level below 55 decibels. Measurements made on the test chamber, therefore, even though they may be made close by as a matter of convenience and at a level considerably above 55 decibels, should be made on the A (40 db) characteristic. The measurements then will be a much better indication of the value of any quieting procedure than if they were made with the B or the C characteristic, since the meter will be operating with a frequency response more nearly duplicating that of the ears of the neighbors under the actual listening conditions.

Physical Measurements

Wherever measurements of actual sound pressure are desired, or where the sound meter is to be used with an analyzer, it is generally desirable to use the C characteristic, which provides substantially equal response over the audio-frequency range. Reasons for this are discussed in Part VII.

PART V — PRACTICAL APPLICATION OF THE SOUND-LEVEL METER

Many details of the operation of sound-level meters are ordinarily overlooked in both instruction books and theoretical discussions. This chapter is an attempt to answer some of the questions most frequently asked in correspondence and which have not already been mentioned in previous chapters.

Acoustic Conditions for Measurements

Part III described the procedure for correcting sound measurements for background noise level. In Part IV microphone placement was discussed. Another important factor that should not be overlooked is the acoustic condition of the room or space in which the measurements are made. Sound, like light, is reflected by some surfaces and absorbed by others. A porous, soft material or heavy fabric will absorb sound much as a black surface absorbs light. Similarly, a hard surface reflects sound as a white surface reflects light. A source of sound in a room may be likened to a source of light. The sound meter measures the sound pressure at any point just as a photoelectric exposure meter measures the light.

To complete the analogy, since sound-level meters have non-directional microphones, it should be assumed that the photoelectric cell of the exposure meter responds equally to light coming from all directions.

The reading of the exposure meter at any point in the room will depend not merely upon the intensity of the light source, but also upon the absorbing capacity of the walls. With completely flat, black walls the only light reaching the exposure meter will be direct from the lamp. With any other kind of walls the actual reading of the exposure meter will depend upon the reflection from the walls as well as the brightness of the lamp.

"Dead" Room Measurements

Exactly the same is true in sound measurements. Hence such measurements, so far as possible, are generally made under conditions of high acoustic absorption in order to avoid additional errors resulting from reflections. Reflections are entirely absent only when measurements are made outdoors at some distance from all buildings or other obstructions, or in a room, all interior surfaces of which are 100% absorbent. In practice, the ideal location does not exist, but it is usually possible to minimize the effects of those reflections which cannot be avoided.

Radiation of Sound

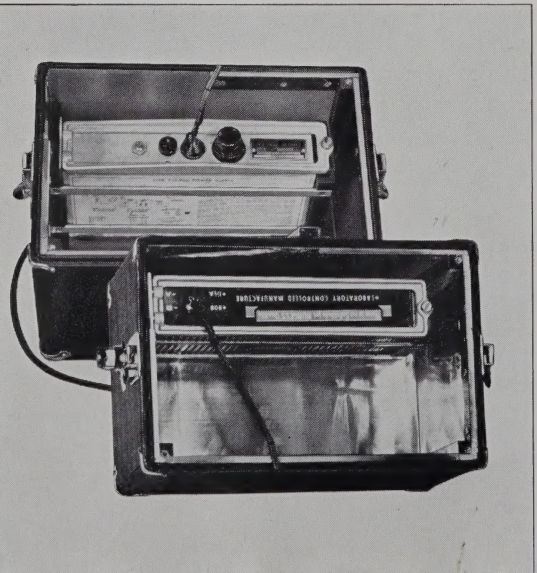
Sound radiated from a small source varies in pressure inversely as the distance from the source. Hence, each time the distance between the sound meter

and the sound source is doubled, the reading of the meter will decrease 6 db if no reflections are present. The sound pressure around a typical machine usually passes through several minima and maxima as the sound meter is moved away, and then approaches the inverse characteristic — that is, will decrease 6 db each time the distance is doubled, providing reflections are not present. This provides a convenient check on whether or not the surroundings are sufficiently non-reflective. Care should be taken in making this test that the background noise does not introduce serious error. This can be checked by turning off the machine under test and noting the reading of the sound meter on background noise alone. If the background noise is louder than 10 db below the machine noise, correction should be made for it.[10]

It is not always possible, particularly with large machines and small rooms, to obtain high absorption, or even to check absorption by the inverse law, as mentioned above. However, the effects of reflection can be minimized by making measurements fairly close to the machine, so that the ratio of direct sound to reflected sound is high. It is customary, therefore, in checking large machinery to make an appreciable number of measurements at a relatively small distance and average them.

[10]See Figure 5.

FIGURE 8. Both the TYPE 1261-A Power Supply Unit and the Burgess type 6TA60 battery may be used interchangeably in the TYPE 759-B Sound-Level Meter, as shown here.



"Live" Room Measurements

In any room the average sound level will build up to an intensity such that the sound energy absorbed equals the sound energy radiated by the source. Hence in a "live" room — that is, one with high reflecting interior surfaces — the sound will build up to a very high level. This is obviously undesirable for ordinary measurements, but in certain applications it is a real advantage. If such a room has irregular or non-parallel wall surfaces, the level at any point is the result of multiple reflections of sound which originated from all sides of the machine under test. Hence the reading represents, in effect, an integration of the total sound radiated by the machine. The "live" room, therefore, may be very useful for *comparative* measurements, as when quieting a particular machine, since a single sound-meter reading taken at a distance from the machine may be used instead of the average of a large number of readings.

Production Testing

As a practical matter, in the production testing of equipment for noise level, it is seldom possible to obtain ideal acoustic conditions. Tests must generally be made under normal plant conditions of noise and acoustic reflection, and, as a

matter of economy, must generally be limited to a few simple measurements.

If the machine under test is fairly noisy and the background noise level at least 10 db lower, it is usually satisfactory to make one or two measurements on each machine at points near the machine which experience has shown provide good indications of the general noise radiated by the machine. This means that, in general, the measurements will be made at the points of maximum noise around the machine and these measurements correlated with data taken on a few similar machines under more nearly ideal conditions.

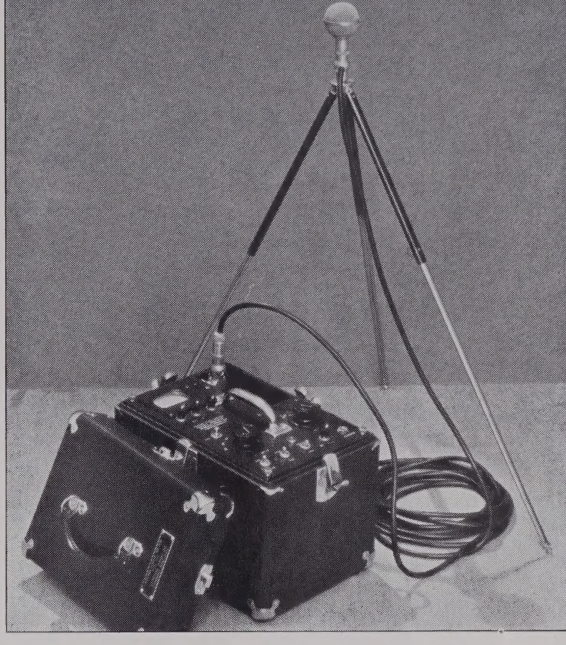


FIGURE 9. TYPE 759-B Sound-Level Meter used with microphone on a tripod.

A-C Power Supply

Where sound-measuring equipment is operating continuously, as in production testing, batteries are undesirable because of the need for frequent replacement. Under these conditions use of a TYPE 1261-A Power Supply Unit is recommended with either the TYPE 759-A or -B Sound-Level Meter.

Vibration Pickup

When measuring fairly quiet devices, such as, for instance, electric clocks or speedometers, ordinary plant noise often makes acoustic measurements impractical unless special soundproof booths, etc., are constructed. In many such cases a vibration pickup may be used in place of the microphone. Sound measurements made under satisfactory acoustic conditions can be correlated with the vibration measurements on any particular type of machine and the vibration measurements then used in actual production testing under plant conditions. In this application the vibration pickup is merely used as a comparison device. Vibration pickups will be discussed in more detail in Part X.

Extension Cable

For the general convenience of the user, the microphone of the TYPE 759-A and -B Sound Level Meters is mounted directly on the instrument, rather than at the end of a cable. This mounting can be a source of error, since the presence of any object in the field around the microphone will distort the field somewhat and cause reflections which will affect the meter readings. Actually, however, on the TYPE 759-A and -B Sound-Level Meters the placement of the microphone above the main body of the instrument is such that the reflection of sounds arriving in a horizontal direction is generally negligible, particularly in the ordinary frequency range of machinery noises. The meter should be used, of course, with the microphone end of the cabinet facing the sound source. The effect of reflections is

further reduced in the TYPE 759-B Sound-Level Meter by the microphone design.

The practicability of mounting the microphone directly on the sound-level meter is shown by the widespread adoption of this method of mounting by various other manufacturers.

An extension cable for the microphone is sometimes necessary. For these applications special cables having good shielding and low losses have been developed. Since a crystal microphone is essentially a generator with a capacitive impedance, use of a long cable which is in effect a capacitive load on the microphone results in a slight reduction in output. A cable correction is accordingly supplied, which should be added to sound-meter readings. The correction is not affected by frequency.[11]

Temperature and Humidity

Most sound measurements are made at normal room temperatures — that is, in the range from 60° to 80°F., but there are some instances where measurements must be made at abnormally high or low temperatures. Definite information regarding the temperature characteristics of microphones is generally lacking, since, as previously pointed out, the microphones were intended primarily for broadcast recording and similar uses, and variations which would be serious in noise measurements are of little importance in such work.

The microphone used on the TYPE 759-B Sound-Level Meter is of the piezo-electric type, utilizing a "bimorph" crystal, which is really two crystals cemented together in such a way that most of the temperature characteristics cancel out. Over the range from 24° to 115° Fahrenheit, cartridges of this type generate a substantially constant voltage at all frequencies up to 2000 cycles. Above this frequency there is some variation amounting to a maximum of ±0.5 db at 3000 cycles and ±1.5 db at 8000 cycles. These variations are well within the normal tolerances on microphones and are unimportant over the frequency range generally encountered in noise measurements.

The characteristic of a crystal microphone which changes most with temperature is its capacitance. The curve shown in Figure 10a shows the average capacitance of a microphone as used on the TYPE 759-B Sound-Level Meter as a function of temperature.

Cable Correction

So long as the microphone operates into a high impedance, this change in capacitance with temperature has little effect upon the output but, as the load on the microphone decreases in impedance, variations due to the internal capacitance of the microphone become more important. The TYPE 759-P21 Cable is normally supplied with an attached celluloid tag, as shown in Figure10b, giving proper corrections for different operating temperatures. This cable is 25 feet long and has a capacitance of 675 micromicrofarads. The correction for operating into other capacitances can be figured from the following formula:

$$\text{db} = 20 \log \left(1 + \frac{C_1}{C_2}\right) \qquad (3)$$

where C_1 is the capacitance of the cable and C_2 is the capacitance of the microphone at the particular temperature. For most practical purposes this can be

[11] With the TYPE 759-B Sound-Level Meter and the TYPE 759-P21 Cable the correction at average temperatures is 2.5 db. With the TYPE 759-A Sound-Level Meter and the TYPE 759-P1 Cable the correction is 1.8 db.

read directly from Figure 10a. The correction does not change with frequency so long as any shunting resistance remains relatively high. The input resistance of the TYPE 759-B Sound-Level Meter is approximately 7 megohms.

The crystal units used in these microphones are coated with a moisture-proof compound to reduce the effects of humidity. As with all Rochelle salt devices, the maximum safe operating temperature is 115°F. At temperatures above 130°F. permanent damage to the crystal results.

Variable Sounds

The panel meter on standard sound-level meters such as the TYPE 759-B (and TYPE 759-A) has definite ballistic characteristics, as specified by the American Standards Association. These standards presumably represent an attempt to obtain a reasonable compromise between the response of the ear to varying or transient sounds and what can be obtained in a practical indicating instrument. It is often desirable, however, to obtain a single reading representing an average sound level by means of a heavily damped meter, and for this reason the TYPE 759-B Sound-Level Meter (and some of the later TYPE 759-A's) is equipped with a slow-fast meter. This is controlled by a switch directly below the meter. The fast position gives the normal A.S.A. characteristic. The slow position provides a heavily damped meter response for averaging varying sounds. On steady sounds the meter will read the same on either position of the switch.

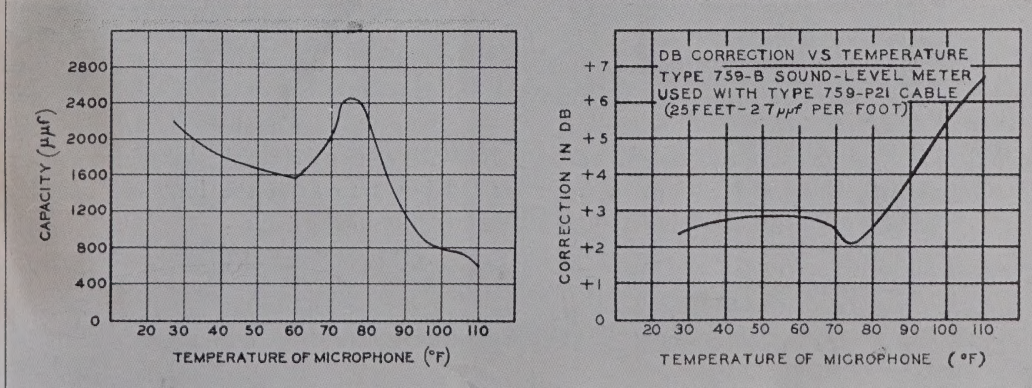
Why Use a Sound-Level Meter Anyway?

This and the preceding chapters have been mainly concerned with the actual practical side of sound-level measurements with no attempt to gloss over the difficulties or possible errors. An instrument can be used most intelligently only when its limitations as well as its advantages are known. It should be realized, however, that the limitations are inherent in the present state of the art and are not caused by cutting corners in the design of the instrument. The TYPE 759-B Sound-Level Meter, in particular, represents the best compromise among the factors of accuracy, convenience, ruggedness and portability which has been devised to date, and its low price is a result of careful design and efficient manufacturing methods.

Experts all agree that readings of a sound-level meter do not always check with a sound jury's estimate of loudness, for many reasons which seem in-

FIGURE 10 (a). Capacitance variation of microphone of TYPE 759-B Sound-Level Meter as a function of temperature.

FIGURE 10 (b). Temperature correction for TYPE 759-B Sound-Level Meter when used with TYPE 759-P21 Cable.



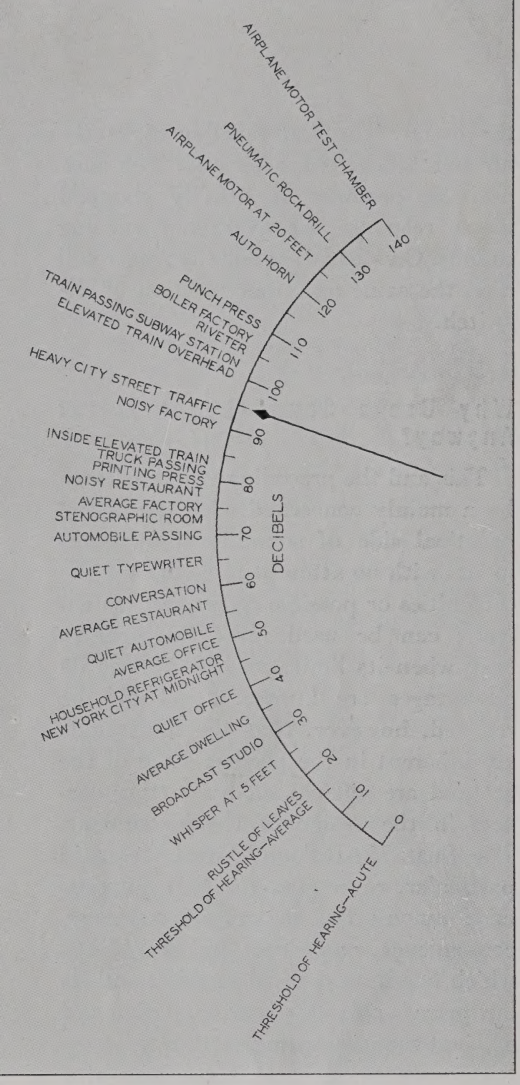


FIGURE 11. Scale of sound levels for typical noise sources.

superable by practical means in the present state of the art. This does not, however, mean that a sound-level meter is useless — quite the contrary. In fact, for many purposes the meter's characteristics are more useful than if they followed the ear exactly.

1. The meter gives a definite numerical reading which can be duplicated quickly, and which can be kept as a permanent record.

2. The meter can distinguish slight changes in level imperceptible to the ear. Several small changes, each one unimportant by itself, can add up to a very definite improvement.

3. The meter's readings are unaffected by the many human variables which enter into any sort of loudness estimates.

4. The frequency characteristic of the meter can be adjusted independently of the level.

5. The meter can, for purposes of physical analysis, etc., provide unweighted readings in terms of actual sound pressures.

6. The meter is unprejudiced by likes or dislikes for particular types of sounds.

These are by no means all the advantages of the sound-level meter, but they are most of the important ones. Only through actual use of the meter can an engineer become fully acquainted with its convenience, accuracy, and usefulness. To one who has used a sound-level meter, it is indispensable.

PART VI—ANALYSIS OF NOISE

Why Analysis?

The sound-level meter measures only weighted or unweighted sound pressure. For a more complete description of the sound, measurements involving pitch and quality are also needed. The usual mathematical concept of a complex sound or vibration is based upon the Fourier system of analysis, which divides any complex waveform into a series of sinusoidal, or pure, waveforms of different pitch or frequency and of definite amplitude and phase relationship. Each of these sinusoidal waveforms contributes to both the loudness and the quality of the sound.

In general, what the ear recognizes as pitch is determined by the frequency of the lowest-frequency sinusoidal component in the complex waveform. The higher-frequency components are generally, but not always, harmonics (that is, integral multiples) of this frequency, and determine the quality or timbre of the sound.

For instance, steady-state notes of the same pitch, but played upon different musical instruments, have the same fundamental frequency and differ only in their harmonic structure or overtones. Similarly, two noises of the same intensity and the same pitch may vary appreciably in the annoyance they cause because of different harmonic makeup or "quality."

A sound analyzer measures the amplitude of each individual frequency component.[12] For steady-state sounds, therefore, measurement of level with the sound-level meter and analysis of harmonic structure with the sound analyzer give a substantially complete description of the sound itself. There are other characteristics which may affect slightly the quality of a sound, but for general purposes it may be said that two steady-state noises of the same level and harmonic structure will sound alike.

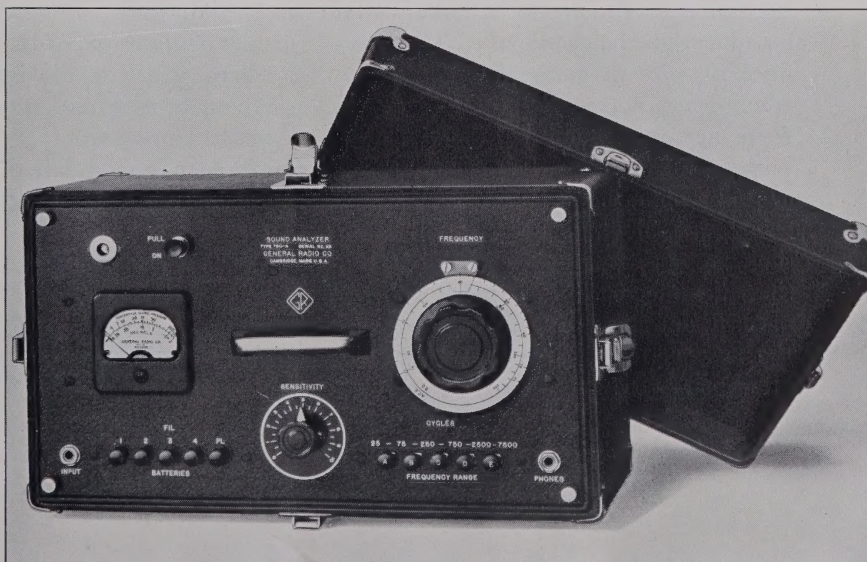
The analyzer shows clearly why different kinds of musical instruments playing the same note do not sound alike. Each has its characteristic timbre, which depends upon the resonances of the instrument itself.

Similarly, the noise generated by any mechanical device depends upon its own resonances. The sound produced by a machine includes not only a fundamental frequency, depending generally upon the machine's speed, but also many other components of higher frequencies, usually determined by the resonant frequencies of the various machine parts and structural elements. Many of these resonances are calculable[13] or measurable by various methods. Hence an analysis of the noise will provide many clues to the source of the various components. When the source of the noise is found, the problem is half solved. Often relatively simple modifications will entirely eliminate the noise.

[12]Except under unusual conditions the phase of the components does not affect the ear and hence is unimportant for purposes of noise measurement.

[13]For instance, see J. P. Den Hartog, "Mechanical Vibrations," published by McGraw-Hill, 1947; S. Timoshenko, "Vibration Problems in Engineering," Van Nostrand, 1937; I. B. Crandall, "Theory of Vibrating Systems and Sound," Van Nostrand, 1926.

FIGURE 12. View of the TYPE 760-B Sound Analyzer with cover removed.



Therefore a sound analysis is useful for two important reasons. In the first place, it provides definite information, which can be recorded for later reference, as to the makeup of the sound. In the second place, the sources of the sound can be identified through their corresponding frequency components, so that definite steps can be taken to reduce the sound through proper redesign of the mechanism.

Classification of Noises

Machinery noises may be divided roughly into two classes. The first includes the fundamental frequency at which the machine is operating and various harmonics thereof, as well as any other components which vary in frequency proportionally with the fundamental. Sounds of this class are generally characterized by the harmonic relationship between the various components and are characteristic of most types of rotating or reciprocating mechanisms, particularly those operating at high speeds. These are the noises commonly referred to as "pitched."

The second class of noises contains those components which are *not* definitely related in frequency to the fundamental speed of the machine. These vibrations are generally caused by shock excitation at the machine fundamental speed or some harmonic of it. They produce a series of damped waves whose components correspond to the natural frequency or harmonics of the vibrating parts, rather than to the machine speed or its harmonics.

The actual frequencies involved in such sounds are seldom clearly defined, since the effects of shock excitation, the natural damping of mechanical parts, the movement of the parts, and the variation of forces impressed upon them cause appreciable frequency variations. Such sounds are commonly referred to as "unpitched" and include rattles, buzzes, and similar noises. Their sound energy is generally spread over frequency bands rather than being confined to discrete frequencies.

The noise of most machines contains both pitched and unpitched components, but usually most of the important sound energy falls into one class or the other. For example, the whine of a dynamo is almost entirely a pitched sound in Class 1. A typewriter, on the other hand, produces noise almost entirely through shock excitation, and hence this noise is an unpitched sound, falling into Class 2.

Unpitched sounds, except in those few cases such as the typewriter, are characteristic mainly of machines which are poorly designed or in poor repair. The presence of strong Class 2 components in the noise produced by a machine of which they are not characteristic is generally an indication of trouble.

Analyzer Characteristics

It is well known that the ease with which a frequency-selective electric circuit can be adjusted to resonance with any particular signal component depends upon the steadiness of pitch of that component. Fluctuation, or frequency modulation, of the pitch beyond the band width of the selective circuit produces an attenuation of the response dependent upon the type and extent of the frequency modulation and upon the characteristics of the selective circuit.[14]

[14]From the mathematical standpoint, frequency modulation produces side bands, just as amplitude modulation does. In frequency modulation strong side bands cover a band width equal to the total frequency swing. These side bands, however, are spaced apart in the frequency spectrum by intervals equal to the modulation frequency, which in machinery sound and vibration problems is generally very low, so that the side bands cannot be measured separately with any practical analyzer now available.

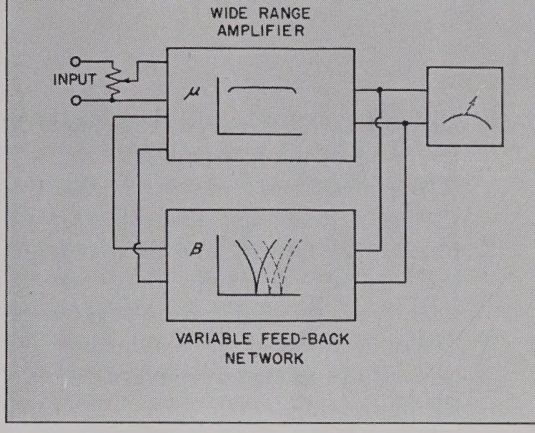


FIGURE 13. Functional block diagram showing the operation of the TYPE 760-B Sound Analyzer. It consists of a high gain amplifier and a frequency-selective feedback network, so designed that the feedback is degenerative at all frequencies except that to which the network is tuned.

Most users of sound-measuring and -analyzing equipment are in agreement that in the ideal noise analyzer the band width of the selectivity curve should be proportional to the frequency to which the device is tuned. For Class 1 sounds this will provide the minimum error, since any attenuation caused by frequency modulation of the sound will be equal for all components, and they will then be measured in their true relative proportions.

For Class 2 sounds it is obviously more difficult to determine the ideal selectivity characteristic, but the constant-percentage type, which widens out in band width proportionally as the frequency is increased, is far more suitable for measuring the unpitched components than an analyzer with razor-sharp selectivity in the high-frequency region. The degenerative type of sound analyzer which has inherently a constant-percentage band width characteristic,[15] has been developed for noise analysis and is generally better adapted for that purpose than the many modifications of heterodyne and other types of analyzers which are also in use. Figure 13 shows the principle of operation of the degenerative-type analyzer.

The General Radio TYPE 760-B Sound Analyzer[16] is of the degenerative type and, because of its unusual circuit, it is both inexpensive and easily portable. Because of the absence of inductances in the design of this instrument and the complete electrostatic shielding of the case, this instrument is quite unaffected by ordinary electromagnetic and electrostatic fields.

Where a heterodyne-type analyzer, such as the General Radio TYPE 736-A, is available, it also can be used for noise analysis of sounds where the pitch is constant and no important unpitched components are present. Where new equipment is to be purchased for industrial noise measurements, however, the TYPE 760-B Sound Analyzer is recommended.

The following instructions apply to the TYPE 760-B Sound Analyzer.

[15] The theory of this circuit was described in "A New Type of Selective Circuit and Some Applications," by H. H. Scott, Proc. I.R.E., Vol. 26, No. 2, February, 1938. See also U. S. Patent No. 2,173,427.

[16] This analyzer was described in "The Degenerative Sound Analyzer" by H. H. Scott, The Journal of the Acoustical Society of America, Vol. 11, No. 2, October, 1939; also "An Analyzer for Noise Measurement," *General Radio Experimenter*, February, 1939.

PART VII—HOW TO USE THE SOUND ANALYZER

Relative Readings

The TYPE 760-B Sound Analyzer is completely self-contained and operated from dry batteries. No battery adjustments are required. Push buttons and a neon lamp on the panel indicate whether or not the batteries have sufficient voltage for satisfactory operation. Complete instructions covering testing and replace-

ment of the batteries will be found in the cover of the instrument.

The analyzer is tuned by means of the large knob and the row of push buttons beneath it. The buttons select the particular frequency range and the knob provides tuning over that range. The calibration is direct reading in cycles per second and may be converted to rpm by multiplying by 60.

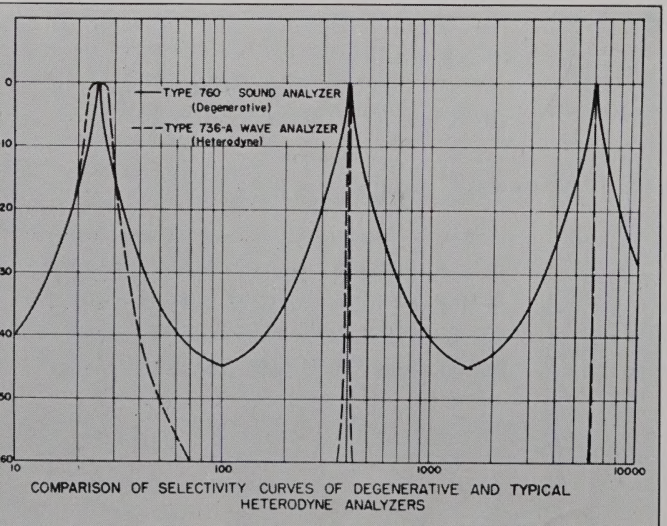
To analyze a sound, connect the input of the analyzer to the output of the sound-level meter by means of the cord provided. Both instruments should be turned on. The level of the sound which strikes the microphone will be indicated directly on the meter on the panel of the sound-level meter. This reading is the total sound pressure. Press Button A on the sound analyzer, which selects the 25-to-75-cycle range, and turn the main dial slowly from 25 to 75 cycles, noting the deflections of the meter on the sound analyzer. Repeat this process, covering the entire range of the instrument by successively depressing Buttons B, C, D, and E and turning the dial around. The instrument is so constructed that the dial may be rotated continuously in one direction, thus facilitating rapid scanning of the entire frequency range.

During this process the sensitivity control of the analyzer should be turned down whenever a component is found which deflects the meter above the 100% (0 db) point, so that the meter reads exactly at this point. This sets the sensitivity such that the analyzer will read 100% on the loudest component in the sound. *Do not change the setting of this control before the analysis is completed.* The analyzer should then be carefully tuned for maximum amplitude on each component (without touching the sensitivity control) and the results recorded. This provides an analysis directly in terms of the loudest component, which is generally, but not always, the fundamental.

The sensitivity control on the analyzer is intended only for use in making the initial setting and it should not be used as a multiplier for the meter or to extend the scale of the meter.

The output voltmeter is calibrated in two ranges: +2 to −30 db, and −12 to −40 db. Auxiliary percentage scales of 0 to 120% and 0 to 24% are also provided, so that measurements can be made in whatever units are most convenient to the operator.

The analyzer is equipped with an output jack for operating a pair of head telephones, thus allowing the user to listen directly to the particular component being measured.[17]



COMPARISON OF SELECTIVITY CURVES OF DEGENERATIVE AND TYPICAL HETERODYNE ANALYZERS

[17] This output can also be used to operate a graphic level recorder. Output level is approximately 0.5 volt open circuit, or 0.3 volt across a 20,000-ohm load.

FIGURE 14. Comparison of the selectivity curves of a degenerative and a heterodyne analyzer. The degenerative analyzer, because of its constant percentage selectivity, is to be preferred for noise analysis.

Absolute Readings

Relative readings are generally sufficient for practical analyses, but if it is desired to have the readings in terms of the absolute sound level rather than referred to the strongest component, proceed as follows:

Plug the sound-level meter into an alternating-current power line and adjust all controls as when calibrating. This will provide a deflection on the indicating meter of approximately +3.

Connect the analyzer to the sound-level meter, tune the analyzer to the power-line frequency and adjust the SENSITIVITY control so that the indicating meter on the analyzer reads 10 db lower than that on the sound-level meter. For instance, if the sound meter reads +3 the analyzer meter should read —7. *Do not readjust the SENSITIVITY control further.* The dial may be marked with a pencil to show the proper setting, if desired.

Disconnect the sound-level meter from the power line and adjust the DECIBELS control of the sound-level meter for normal measurement of the sound with the indicating meter showing a deflection between 0 and 10 (except, of course, for levels below 30 db). The analyzer may then be tuned to each individual component in the normal manner. Do not change the setting of the sensitivity control on the analyzer. The absolute level of each component will be indicated directly by the algebraic sum of the setting of the DECIBELS switch on the sound-level meter and the decibels reading of the indicating meter on the analyzer, plus 10 db. The DECIBELS switch on the sound-level meter should not be used to increase the deflection of the meter on the analyzer on low amplitude components since this would overload the output circuits of the sound-level meter and cause distortion.

Choice of Network

For sound or noise analysis, the C curve (flat) should generally be used. This gives a direct physical measurement of the relative intensity of each component, and any weighting as a function of frequency can be readily applied as desired. In some cases, the low-frequency components may dominate without being the components of greatest interest. Then the use of the A or the B curve may attenuate the low-frequency components sufficiently to permit one to obtain a more satisfactory comparison.

PART VIII

MAXIMUM ACCURACY IN NOISE MEASUREMENTS

Previous chapters have covered the theoretical and practical considerations involved in making ordinary sound level measurements and analyses. The instruments used, the TYPE 759-B Sound-Level Meter and the TYPE 760-B Sound Analyzer, have been designed in accordance with accepted standards and are direct reading. For the most part, therefore, no auxiliary calibration or correction data are required.

In general, the accuracy of direct-reading measuring equipment can be improved by the use of individual calibration data, and this is particularly true in the case of sound-measuring equipment where, as has been previously pointed out, the microphone characteristic may deviate appreciably from theoretical perfection. This chapter, therefore, is devoted to information which the average user may not need and which is sel-

dom available from manufacturers in published form. The necessary space is being devoted to it here on the theory that the user of instruments should know not only their limitations, but how these limitations may be minimized or overcome in those few cases where it may be necessary.

On average sounds, involving mainly frequencies between 60 and 3000 cycles, different makes and models of sound-level meters meeting the A.S.A. standards will generally read alike within a db or so, which is about all that can be expected in the present stage of microphone development. The degree to which the theoretical response curves must be approximated to meet the A.S.A. requirements was shown by the tolerances in Figure 2.[18] The so-called "noise of general character" for which a sound meter is corrected was shown diagrammatically in Figure 3.

There are, unfortunately, certain individual applications where the sound being measured differs greatly from the general noise of the A.S.A. standards, and different types of sound-level meters may not read exactly alike. In such cases the question of which meter is most nearly accurate is mainly academic and is liable to lead to unwarranted conclusions since the actual error will depend upon the characteristics of the sound. All microphones of the types commonly used with sound-level meters exhibit marked irregularities in the response curve above 3000 cycles, and some types are also irregular in the low-frequency region. The best procedure, therefore, is to correct for these irregularities, so that the reading will be the same as that which would be obtained by a theoretically perfect, but practically unattainable, sound-level meter — that is, one which followed the design objective curves exactly. This can be done when the response of the equipment at each frequency and the analysis of the sound are definitely known. This requires the use of a calibrated sound-level meter and an analyzer.

A microphone can of course be calibrated with respect to frequency, thus providing a curve showing the response at any frequency throughout its range. A complete calibration covering the whole sound-level meter, including the microphone, can be obtained from the sound-level meter manufacturer or the Bureau of Standards. This provides the user with an exact knowledge of the sensitivity of his meter under a given set of conditions and at definite frequencies. In order to make use of the calibration it is necessary to know also the frequencies of the components which comprise the noise being measured. These may be determined with the sound analyzer. Analyzers,

[18]See page 3.

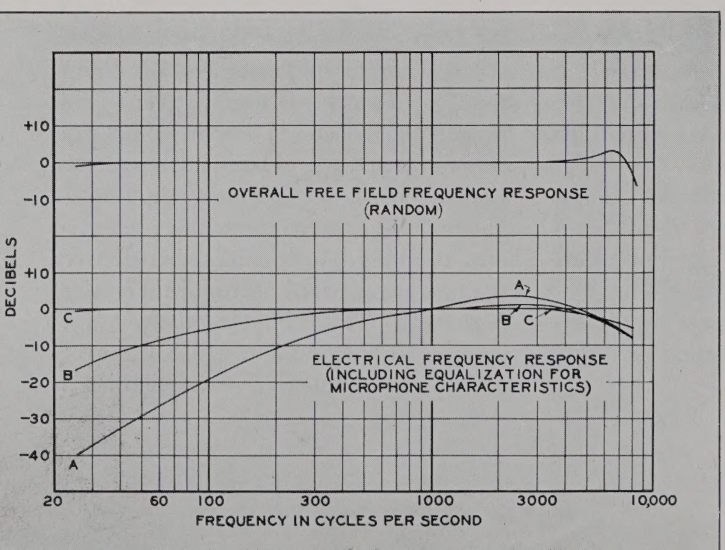


FIGURE 15. Typical average acoustical and electrical calibration curves for TYPE 759-B Sound-Level Meter.

like sound-level meters, do not have perfectly smooth frequency characteristics, but the variations are generally small compared to those of the sound-level meter. However, for use with a calibrated sound-level meter, the analyzer should also be calibrated. This can be done by the manufacturer, or by the user, if he has a good audio-frequency oscillator available.

Sound-Level Meter Calibration

Figure 15 shows a typical sound-level meter calibration as supplied by the General Radio Company. The upper curve represents the over-all acoustical free-field response of the sound-level meter as determined in accordance with the A.S.A. standards, with the weighting switch set at the C position. The relatively smooth frequency response throughout the medium- and low-frequency regions is characteristic of the piezo-electric type of microphone. The lower curves represent the electrical characteristics of the meter, exclusive of the microphone, for the three different weighting curves. These are similar to the curves shown in Figure 2 except for the modifications which are made to compensate for the microphone characteristics. Obviously, additional acoustical curves for the A and B weightings similar to that shown for the C can be plotted from these data, if desired, by merely applying the differences between the three curves for the electrical characteristics to the acoustical C curve.[19]

With all microphone calibrations it should be remembered that the response of the microphone varies somewhat with direction, particularly in a vertical plane. The acoustical curve shown in Figure 15 represents the random response obtained by averaging the characteristics measured at different angles, as specified by the A.S.A. Bureau of Standards calibrations, unless the customer specifies otherwise, are generally made at the so-called 90° angle of incidence (zero degrees is straight down toward the top of the microphone), which corresponds to a sound arriving at the microphone in a horizontal direction. The microphones are normally used in this position, but under practical conditions, as a result either of the size of the sound source or the presence of considerable reflected sound, much of the sound reaches the microphone at angles other than 90°. This is the reason for the A.S.A.'s averaging procedure.

Figure 16 shows the response of a typical TYPE 759-B Sound-Level Meter to sounds reaching the microphone from different directions. All sound-level meters using so-called non-directional microphones will have this general type of characteristic. The response of such microphones is generally symmetrical around a vertical axis. In order to make best use of a calibration curve, therefore, the angle at which the calibration was made should be known. Figure 17 shows the 90° response of a TYPE 759-B Sound-Level Meter microphone in terms of the random response. This curve is typical of this particular type of meter and may be used for an additional correction where the user is certain that the sound is all reaching the microphone in a horizontal direction. This applies only when the microphone is placed at the same horizontal level as the sound source and the surroundings are substantially non-reflecting, so that only direct sound is reaching the meter.

[19] Bureau of Standards calibrations are plotted in terms of correction rather than actual sensitivity. Hence a Bureau calibration corresponding to the upper curve C in Figure 15 will be inverted. The Bureau does not measure the electrical frequency characteristics as shown in Figure 15, but the *differences* between these electrical curves can generally be obtained sufficiently accurately by taking the *differences* between the design objective curves in Figure 2.

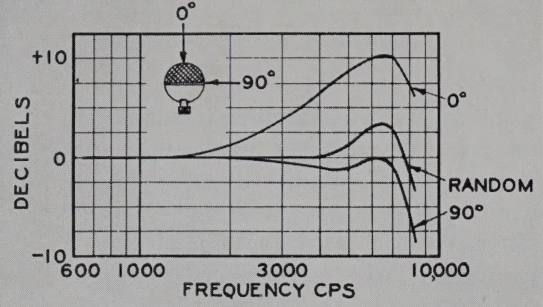


FIGURE 16. Typical curves showing the response of average TYPE 759-B Sound-Level Meters to sounds reaching the microphone at various angles. The random response which corresponds with the A.S.A. Standards represents the over-all characteristic, assuming that the sound arrives equally at all angles in a vertical plane.

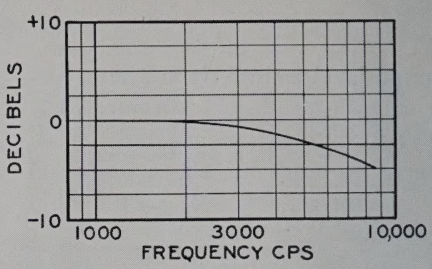


FIGURE 17. Microphone calibrations, when supplied, are for random response. Under conditions where all the sound reaches the microphone from the horizontal (90°) direction the above correction can be applied to the random calibration curve in order to obtain better accuracy at high frequencies. This curve is the difference between the random and 90° curves of FIGURE 16.

Caution: It is obvious from Figure 16 that so-called non-directional microphones have abnormal sensitivity to high frequencies at the zero degree angle. When measuring sounds involving strong high-frequency components, therefore, care should be taken that the sound strikes the microphone at an angle of 45° or greater, in order to avoid undue influence of these high-frequency components on the total reading. This is ordinarily taken care of automatically, since the microphone is normally used at or near the 90° angle — that is, side toward the source.

Sounds reaching the microphone by reflection from surrounding objects will arrive at angles other than 90°. So long as this represents a random distribution, the process of averaging used in calibrating the microphone will tend to cancel errors. However, if by any chance some hard surface directly above the microphone reflects or focuses the high frequencies downward onto the microphone, serious errors may result. This possibility of error can be eliminated by covering such surfaces, if present, with felt, carpeting, or other absorbent material. Since only high frequencies are involved, it is a relatively simple matter to absorb them.

It is also possible, in specialized applications where strong high-frequency components are present and where equality of response in all directions in a horizontal plane is not necessary, to use the microphone at the zero degree angle — that is, aimed at the sound source and thus obtain a certain amount of directivity. A special calibration is necessary for this work, however, since the variations in microphone response as the zero-degree angle is approached are sufficiently large to make prediction of the zero-degree response on the basis of the random or 90° response of doubtful value. Figure 16 represents the average of a number of microphones. In any individual microphone the spread between the zero-degree and random reponse curves will vary enough so that the errors involved in applying these average curves would probably be as large as that caused by high-frequency reflections when using the microphone in the usual 90° position.

Using the Calibrated Sound-Level Meter

When the calibrated sound-level meter is used with an analyzer, correction for the microphone characteristic is relatively simple. The noise measurement

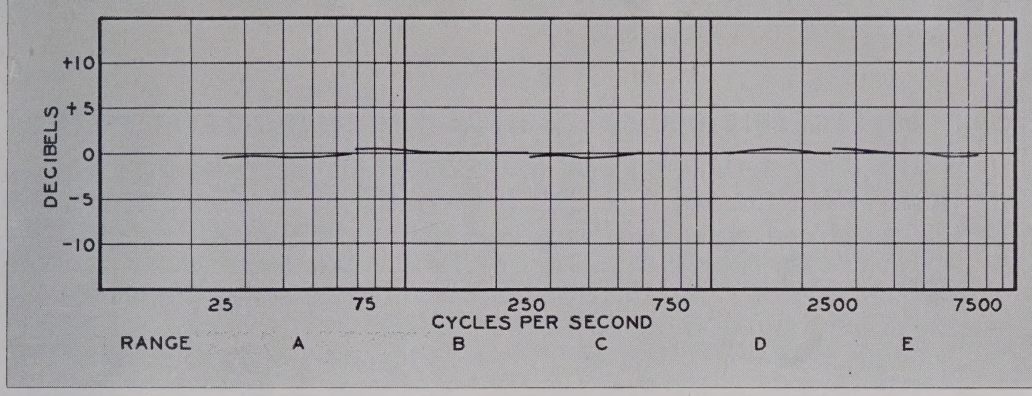


FIGURE 18. Typical response curve of TYPE 760-B Sound Analyzer. A calibration of this type may be made easily by anyone having a satisfactory audio-frequency oscillator and vacuum-tube voltmeter or other indicating device. All that is necessary is to maintain a constant voltage at the input of the analyzer, tune the oscillator to various frequencies throughout the range and at each frequency tune the analyzer to exact resonance and read the indicating meter.

and analysis should be made in the usual manner. If any of the important sound components occur at frequencies at which the sound meter deviates appreciably from the design objective curve (that is, the acoustical curve C in Figure 15 deviates substantially from a straight line), suitable corrections can be made.

For instance, assume a sound consists almost entirely of a strong component at 7000 cycles. From Figure 15 we find that the meter is 3 db too sensitive at this frequency, and from Figure 18 we find that the analyzer is ½ db low in sensitivity at this frequency. Thus we know that our reading is 2.5 db too high.

For complex sounds the procedure is somewhat longer, but not complicated. Each component falling at a frequency where the meter calibration shows an appreciable irregularity should then be corrected as described above. Correction will then be

$$\text{db} = 10 \log_{10} \frac{S_2}{S_1} \qquad (4)$$

where S_2 is the sum of the squares of the relative sound pressures of the components, corrected as necessary, and S_1 is the sum of the squares of the relative sound pressures of the components *before correction* for sound-level meter frequency characteristics, but with the analyzer correction applied.

In general, all components lower than 10% of the loudest may be neglected in computing S_2 and S_1. However, it is important that the same components be used in computing both S_2 and S_1.

Relative sound pressures may be read directly from the percentage scale of the TYPE 760-B Analyzer. When S_2 is smaller than S_1 the correction will be negative, since the actual sound level will be lower than the measured sound level. This correction should be applied to the sound-level meter reading on the particular sound only.[20]

It is also possible, of course, by means of the analyzer to measure the absolute amplitude of each component individually in terms of decibels, convert all of these figures to relative *power* ratios, add them together and convert the sum back to decibels; and the answer should be the same. The first procedure outlined above is generally more accurate, however, since it automatically includes many low-amplitude components or random noise which may not show up in an analysis, but which, when added together, may constitute a measurable part of the total sound energy. It is also somewhat simpler, requiring less calculation.

[20] This may be read directly from the General Radio Table I by considering $\frac{S_2}{S_1}$ as a power ratio.

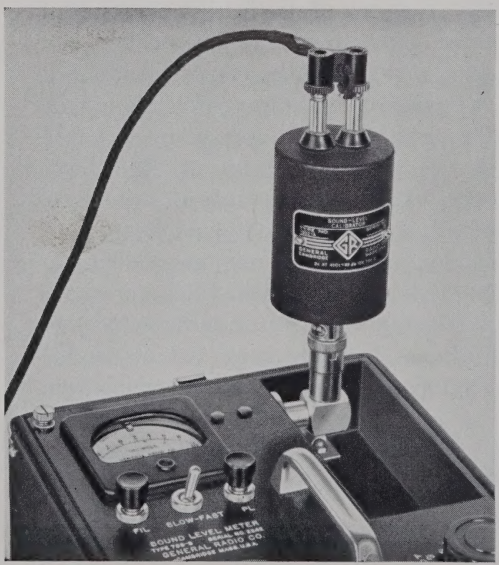
AN ACOUSTIC CALIBRATOR FOR THE SOUND-LEVEL METER

Although a check on the calibration of the electrical circuits is provided in the sound-level meter, the long-time stability of the microphone calibration becomes important when the meter is continually used to check compliance with test specifications for noise.

The General Radio TYPE 1552-A Sound-Level Calibrator was developed in response to a number of requests for a simple and convenient means for making this acoustic check. The calibrator, illustrated in Figure 18a, comprises a small, stabilized, and rugged loudspeaker mounted in an enclosure which fits over the microphone of the sound-level meter. The chamber is so designed that the acoustic coupling between loudspeaker and microphone is fixed and can readily be repeated. The level is high enough so that readings are unaffected by normal background noises.

The calibrator can be operated from any audio oscillator having reasonably good waveform (harmonic content should be 5% or less) and capable of supplying 2 volts at 400 cycles across an impedance of 1 μf in parallel with 2000 ohms. Most users will find that they have available a suitable audio oscillator and a voltmeter for use with the calibrator.

FIGURE 18a. View of Type 1552-A Sound-Level Calibrator in operating position on microphone of Type 759-B Sound-Level Meter.



This calibrator checks the level of the microphone at 400 cycles; it does not give a calibration over a wide frequency range. However, since the piezo-electric microphone used on the TYPE 759-B has a very uniform response from 20 cycles to 1000 cycles, this level check is satisfactory for most machinery noise and for the setting of the sound-level meter according to the specification of A.S.A. Bulletin Z24.3–1944, using the spectrum of Figure 3.

With the TYPE 1552-A Sound-Level Calibrator as an accessory, the scope and usefulness of the TYPE 759-B Sound-Level Meter will be improved. If the sound-level meter is being used in a prolonged series of tests, the calibrator will serve as a periodic monitor of over-all calibration. This will prevent small changes in sensitivity from passing unnoticed and, even more important, will show up a damaged microphone before much useless data have been taken. The use of the calibrator will not, in general, improve the absolute accuracy of the sound-level meter, but it should prove to be a valuable aid in assuring constancy of calibration throughout a period of measurements or between groups of measurements which may be separated not only in time but in distance.

PART IX — VIBRATION AND SOUND

That sound and mechanical vibration are related is such a simple concept as to seem hardly worth mentioning. However, the relationships between these two phenomena and, in particular, their effects upon human beings are very complicated indeed.

Most of us use the terms sound and vibration in broad and overlapping senses, but for the purposes of this discussion it is best to keep to rather narrow meanings. Sound, therefore, will be considered as air-borne vibrations of an audible frequency. The term vibration will be used to mean mechanical vibrations or vibrations occurring in solids. The frequency ranges for sound and vibration as thus defined are roughly the same, excepting that important vibrations may also be present considerably below the lower frequency limit of hearing, and satisfactory vibration-measuring equipment must operate at frequencies as low as 2 or 3 cycles per second.

The reasons for measuring or reducing vibration are generally two. In the first place, as is generally realized, audio-frequency vibrations of solids transmit sound vibrations to the air, thus creating noise. The process of quieting a machine or device generally includes, therefore, a study of the mechanical vibrations involved.

In the second place, serious vibration may cause actual failure which, in the cases of heavy machinery or airplanes, for instance, may have fatal consequences. Vibration, then, is not only a source of noise, but often a source of real danger. The present perfection of high-speed planes, ships, and automobiles could never have been achieved without a thorough study of vibration, its cause, measurement, and cure.

Displacement, Velocity, and Acceleration

Vibration, like linear and angular motion, can be measured in terms of displacement, velocity, and acceleration. The easiest measurement to understand is that of displacement. In some cases where the displacement is large it can be measured directly with a ruler.

In its simplest case the displacement may be considered as simple harmonic motion, that is, a sinusoidal function having the form

$$x = A \sin \omega t \qquad (5)$$

where A is a constant, ω is 2π times the frequency, and t is the time. The maximum peak-to-peak displacement will be $2A$, and the r-m-s (sometimes loosely spoken of as the average) displacement will be $\frac{1}{\sqrt{2}} A$. The "average double amplitude" (r-m-s) will be $\sqrt{2}A$.

Displacement, however, is not always the property of the vibration that is required in practical problems. A mechanical part radiating sound may be compared to a loudspeaker. In general the *velocities* of the radiating part (which corresponds to the cone of the speaker) and the air directly next to it will be the same, and, so long as the distance from the front of the part to the back is large compared to one-half of the wavelength of sound in air, the actual sound pressure generated in the air will be proportional to the velocity of the vibration. The sound energy radiated is the product of the velocity squared times the resistive component of the air load. Under these conditions, particularly where noise is important, it is the velocity of the vibrating part and not the displacement which is of greatest importance.

The velocity is the first derivative of

the displacement, so that for the simple harmonic vibration in Equation (5) the velocity is

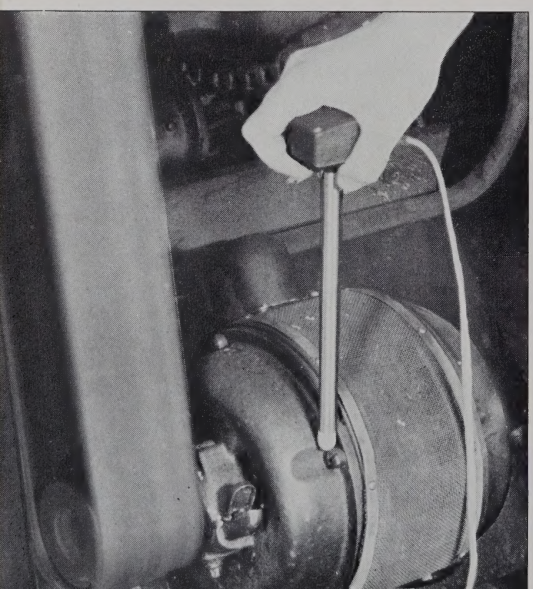
$$v = \frac{dx}{dt} = \omega A \cos \omega t \qquad (6)$$

Thus the velocity is proportional not only to the displacement but also to the frequency of the vibration.

In many cases of mechanical vibration, and particularly where mechanical failure is a consideration, the actual forces set up in the vibrating parts are important factors. Newton's laws of motion state that the acceleration of a given mass is proportional to the applied force, and that this force produces a resulting reacting force which is equal but opposite in direction. Any stresses and strains set up in a vibrating member, therefore, will be proportional to the acceleration of the vibration, which is the second derivative of the displacement. Acceleration measurements are important where vibrations are sufficiently severe to cause actual mechanical failure. Therefore,

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = -\omega^2 A \sin \omega t \qquad (7)$$

FIGURE 19. For most measurements the vibration pickup can be held in the hand.



The acceleration, therefore, is proportional to the displacement and to the square of the frequency.

There is another use for acceleration measurements. The analogy cited above concerning the loudspeaker covers the usual case where the cone or baffle is large compared to the wavelength of the sound involved. In most machines this relationship does not hold, since relatively small parts are vibrating at relatively low frequencies. This may be compared to a small loudspeaker without a baffle. At low frequencies the air may be "pumped" back and forth from one side of the cone to the other with a very high velocity, but without building up much of a pressure or radiating much sound energy because of the very low air load, which has a reactive mechanical impedance. Under these conditions the acceleration measurement provides a better measure of the amount of noise radiated than does a velocity measurement.

To summarize, therefore, displacement measurements are used only in those few instances where the actual amplitude of motion of the parts is important. This would include, in particular, those cases where large amplitude of motion might actually cause parts to strike together, thus causing damage or serious rattle. Velocity measurements are generally used in noise problems where the radiating surfaces are comparatively large with respect to the wavelength of the sound. Acceleration measurements are the most practical where actual mechanical failure of the parts involved is of importance, and in most noise problems, particularly those involving small machinery. A vibration meter, therefore, should be able to measure all three vibration characteristics.

The above equations, (5), (6), and

(7), represent only sinusoidal vibrations, but, as in the case of complex sound waves, complex periodic vibrations can also be represented as a Fourier series of sinusoidal vibrations. These simple equations may, therefore, be expanded to include as many terms as desirable in order to express any particular type of vibration.[21] It will be noted that, since velocity is proportional to frequency, and acceleration is proportional to the square of the frequency, the higher frequency components in a vibration are progressively more important in velocity and acceleration measurements than in displacement readings. The effective reading of the vibration meter on a complex wave is equal to the square root of the sum of the squares of the components which gives further emphasis to the higher amplitude components.[22]

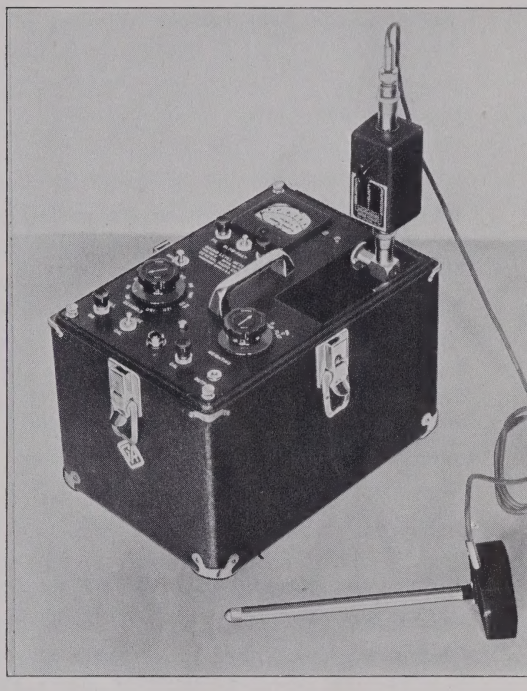


FIGURE 20. The control box and vibration pickup connect to the sound-level meter in place of the microphone.

[21] General equations corresponding to (5), (6), and (7) are, respectively:

$$x = A_1 \sin(\omega_1 t + \alpha_1) + A_2 \sin(2\omega_1 t + \alpha_2) + A_3 \sin(3\omega_1 t + \alpha_3) + \cdots \quad (5a)$$

$$v = \frac{dx}{dt} = \omega_1 A_1 \cos(\omega_1 t + \alpha_1) + 2\omega_1 A_2 \cos(2\omega_1 t + \alpha_2) + 3\omega_1 A_3 \cos(3\omega_1 t + \alpha_3) + \cdots \quad (6a)$$

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = -\omega_1^2 A_1 \sin(\omega_1 t + \alpha_1) - 4\omega_1^2 A_2 \sin(2\omega_1 t + \alpha_2) - 9\omega_1^2 A_3 \sin(3\omega_1 t + \alpha_3) - \cdots \quad (7a)$$

where α_1, α_2, α_3, etc., are the relative phase angles of various harmonics and $\omega_1 = 2\pi$ times the fundamental frequency.

[22] The vibration meter reading of displacement corresponding to (5a) would be

$$|x| = \frac{1}{\sqrt{2}}\sqrt{A_1^2 + A_2^2 + A_3^2 + \ldots} \quad (5b)$$

The velocity and acceleration readings would be, respectively

$$|v| = \frac{\omega_1}{\sqrt{2}}\sqrt{A_1^2 + 4A_2^2 + 9A_3^2 + \ldots} \quad (6b)$$

$$|a| = \frac{\omega_1^2}{\sqrt{2}}\sqrt{A_1^2 + 16A_2^2 + 81A_3^2 + \ldots} \quad (7b)$$

PART X—THE VIBRATION METER

Vibration Pickup with the Sound-Level Meter

For some years a vibration pickup has been available as an accessory for the General Radio Sound-Level Meter. The pickup, which responds to mechanical vibrations, is merely substituted for the microphone, and the sound-level meter used otherwise in a normal fashion. With the TYPE 759-B Sound-Level Meter the

TYPE 759-P35 Vibration Pickup and the TYPE 759-P36 Control Box are used. The pickup itself is of the inertia-operated piezo-electric type, which responds to acceleration.[23] The control box, which connects between the meter and the pickup, provides electrical integrating circuits. The integrating circuits allow the conversion of this response for reading velocity or displacement. This combination of pickup, control box, and sound-level meter provides a convenient and inexpensive way for owners of sound-level meters to make vibration measurements within the audio-frequency range. However, it should be remembered that the sound-level meter circuits were intended only to respond down to 25 cycles, and consequently this combination is not suitable for measuring lower-frequency vibrations.

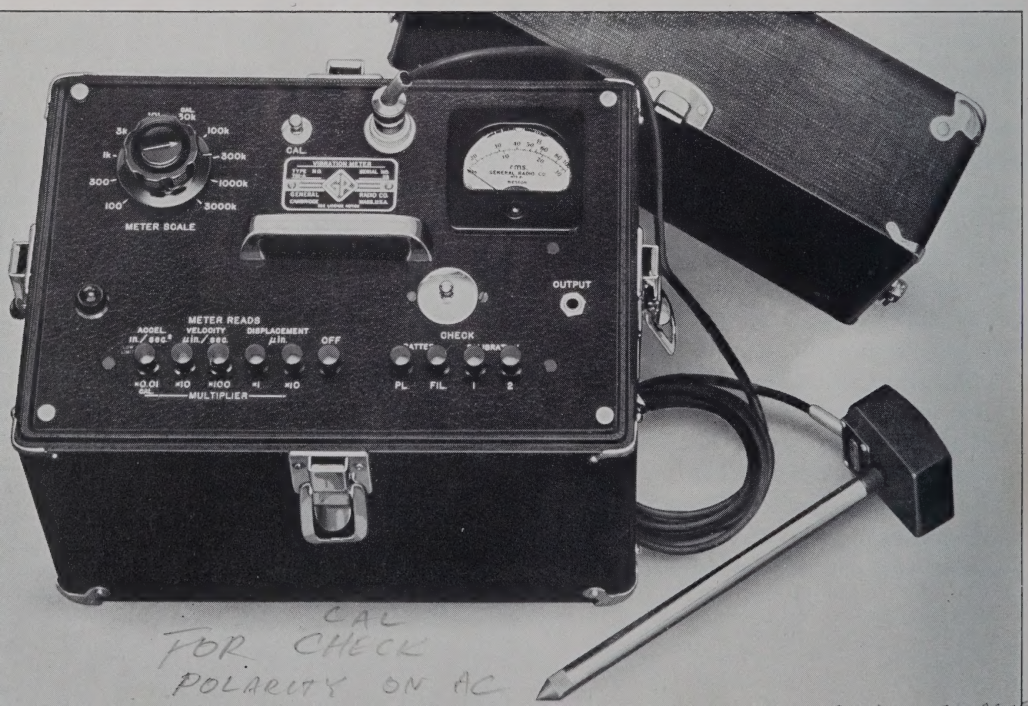
Also, the sound-level meter reads in terms of decibels, which must be converted to other units if the readings are to mean anything in terms of vibration amplitude, velocity, or acceleration. A calibration chart is provided with each control box giving the proper correction figures for that pickup and control box when used with a particular sound-level meter. By means of these data plus a decibel table (supplied in the instruction book), the readings may be converted readily to the more logical units of micro-inches, micro-inches per second, or inches per second per second.

The Type 761-A Vibration Meter

For low-frequency vibrations, or where a large number of accurate observations must be made with a maximum degree of convenience, an instrument designed particularly for vibration measurements is desirable. The TYPE 761-A Vibration Meter is similar in many respects to the TYPE 759-B Sound-Level Meter. It is mounted in a case of

[23] In this type of pickup the crystal is deflected by its own inertia when the pickup is subjected to vibration. The voltage generated is proportional to the actual force exerted on the crystal which is proportional to the acceleration.

FIGURE 21. TYPE 761-A Vibration Meter, designed particularly for machinery vibration problems, covers the frequency range from 2 to 1000 cps (120-60,000 rpm).



nearly the same size, operates from the same size battery, and has a similar mechanical construction, including the free-floating tube shelf. However, the vibration meter was intended to take full advantage of the maximum frequency range of the piezo-electric type of pickup, which extends smoothly from 2 to 1000 cycles per second. Also, the meter is calibrated directly in terms of the r-m-s displacement, velocity, and acceleration and indicates these, respectively, in micro-inches, micro-inches per second, and inches per second per second.[24]

Since the vibration pickup used with this meter is of the acceleration type, two stages of electrical integration are necessary to provide the various types of response. Because the integrating circuits are built in as part of the amplifier, better performance is possible than with a control box attachment. Figure 22 shows the electrical frequency characteristics of the vibration meter excluding the pickup. Figure 23 shows the over-all characteristic in terms of relative response for a constant-displacement vibration in terms of frequency. The irregularities above 1000 cycles are due to natural resonances in the pickup, but it will be noted that the average response is actually quite useful to 2000 cycles or higher. These figures show graphically how the integration process attenuates the higher frequencies with respect to the lower frequencies.

Figure 24 shows the actual effect of the electrical integration on a particular waveform. The square waveform of Figure 24a has strong harmonics. After two steps of integration the result in Figure 24c is approaching sinusoidal waveform.[25]

[24]The TYPE 761-A Vibration Meter is completely described in "A General-Purpose Vibration Meter" by H. H. Scott, Journal of the Acoustical Society of America, Vol. XIII, No. 1, pp. 46–50, July, 1941. A brief description is also included in the General Radio *Experimenter*, Vol. XVI, No. 1, pp. 1–8, June, 1941.

[25]The waveforms shown in Figure 24 may be represented by the following Fourier series:

$$\text{(a)}\quad a = -\omega_1^2 A \sin \omega_1 t - \frac{\omega_1^2 A}{3} \sin 3\omega_1 t - \frac{\omega_1^2 A}{5} \sin 5\omega_1 t - \cdots$$

$$\text{(b)}\quad v = \int a\,dt = \omega_1 A \cos \omega_1 t + \frac{\omega_1 A}{3^2} \cos 3\omega_1 t + \frac{\omega_1 A}{5^2} \cos 5\omega_1 t + \cdots$$

$$\text{(c)}\quad x = \int v\,dt = \iint a\,dt = A \sin \omega_1 t + \frac{A}{3^3} \sin 3\omega_1 t + \frac{A}{5^3} \sin 5\omega_1 t + \cdots$$

These correspond, respectively, to Equations 7, 6, and 5, and to Equations 7a, 6a, and 5a in Note 21. Note that for this particular waveform, while the acceleration equation gives 33% third harmonic, the displacement one gives only 3.7%.

PART XI — HOW TO USE THE VIBRATION METER

Operating Instructions

Like the sound-level meter, the vibration meter has an instruction sheet fastened in the cover which covers the actual operations involved in adjusting and reading the instrument. A knob marked METER SCALE provides in effect a multiplier for the indicating instrument. The red meter scale should be used with the red positions of the knob and the black scale with the uncolored positions. The reading of the control in all cases represents the full-scale deflection of the meter, so that it is merely necessary to add decimal places to the meter reading.

In addition, there is a row of five push buttons to select acceleration, velocity,

TO OBTAIN READING

and displacement response. For each of the latter two characteristics two buttons are provided. The normal buttons are those which provide a low-frequency limit of 2 cycles. The extra buttons, which are so marked, provide a low-frequency limit of 10 cycles, which, however, allows an increase in sensitivity of the meter by a factor of 10 : 1. This is a great advantage for measuring low-amplitude vibrations such as occur, for instance, in clocks, speedometers, and other small mechanisms. Such vibrations seldom have any important components below 10 cycles. Below each button is engraved a multiplying factor (always a multiple of 10) which should be applied to all readings when that particular button is used.

Push buttons are also provided for checking the battery and the calibration.

Sensitivity of Vibration Meter

The TYPE 761-A Vibration Meter will measure displacements as low as 16 micro-inches, velocities as low as 160 micro-inches per second, and accelerations as low as 0.160 inches per second per second.[26]

[26]The displacement and velocity figures are for a low frequency cut-off at 10 cycles. These limits are multiplied by 10 when the full range down to 2 cycles is used.

FIGURE 22. Electrical frequency response of the TYPE 761-A Vibration Meter showing effects of integrating circuit.

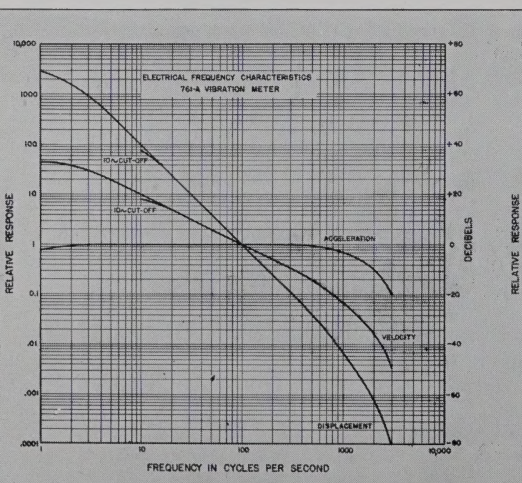
Pickup Placement

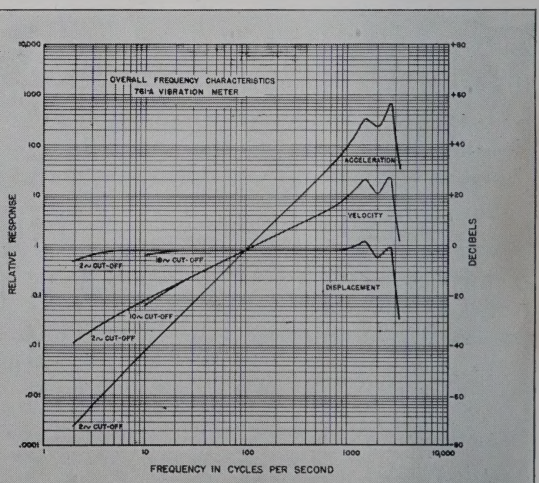
The pickup responds most strongly to vibrations perpendicular to its front surface (the surface with the nameplate). A threaded socket ($\frac{1}{4}$" — 28th) is provided on this surface so that the pickup may be bolted or clamped in any desired fashion. A conical and a rounded tip are also provided, and a long metal probe, all of which fit the threaded socket. The tips may be fastened directly to the pickup or to the end of the probe. By these means it is generally possible to hold the pickup against a vibrating surface or part so that it will pick up the vibration satisfactorily. Sufficient pressure should be used on the pickup so that it follows the vibration accurately without chattering, but care should be taken not to push so hard as to affect materially the vibration itself. Figure 19 shows how the pickup is normally used with the probe. For accurate reading the pickup should always be held or mounted so that its front surface is perpendicular to the direction of vibration.

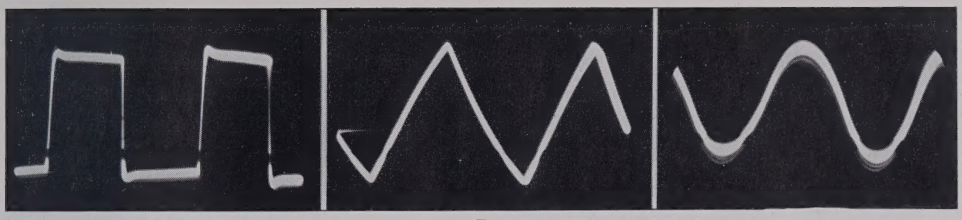
Characteristics of Pickup

As with all Rochelle salt devices, the maximum safe operating temperature for the vibration pickup is 115°F. Tem-

FIGURE 23. Over-all response of the TYPE 761-A Vibration Meter including the vibration pickup.







a b c

FIGURE 24. Illustrating the operation of the integrating circuits in the vibration meter (a) shows a square wave as transmitted by the amplifier when set for acceleration measurements, (b) shows the wave after one stage of electrical integration for velocity measurements, (c) shows the result of two stages of integration as used for displacement measurements.[25]

peratures above 130°F. result in permanent damage to the pickup. Measurements can be made on hotter machinery providing they are made quickly enough so that the pickup does not become heated.

At lower temperatures the temperature characteristics of the pickup are similar to the piezo-electric microphones (see Part V). The actual capacitance of the pickup is approximately 0.005 microfarad. The usual short cable supplied on the pickup does not require a temperature correction, but if a long cable is used the Equation (3) in Part V may be used.[27]

The pickup should not be subjected to accelerations greater than 10 times that of gravity (10g).[28]

Choice of Characteristic

The field of vibration measurement is not as well standardized as that of sound measurements. The choice among displacement, velocity, and acceleration generally depends upon the use for which the data are needed and the considerations mentioned in Part IX. Typical examples of applications for the different types of measurements are as follows: Displacement measurements are widely used in measuring ship vibrations and vibrations in heavy machinery. Velocity measurements are used for measuring sound transmission through walls, the sound radiated by large surfaces such as power transformer shells, etc. Acceleration measurements are used in most machinery noise problems or where parts are liable to fail as a result of the vibration.

In all cases it should be remembered the acceleration measurements give the greatest emphasis to the high frequencies and displacement measurements to the low frequencies.

Applications of the Vibration Meter

All designers of airplanes, ships, and other expensive or elaborate structures, particularly where vibration may be dangerous, carefully calculate the vibratory conditions as a part of the design work.[13] Such calculations, however, generally involve assumptions which cannot always be rigidly justified, and measurements are necessary on the com-

[27]For this purpose the capacity values in Figure 10(a) may be multiplied by two. Figure 10(b) will also apply if a cable of approximately 1350 $\mu\mu f$ is used. These figures are in Part V.

[28]On the calibration of the vibration meter this is equivalent to an acceleration of 3900 inches per second per second, a velocity of $\frac{6.3 \times 10^5}{f}$ micro-inches per second, or a displacement of $\frac{10^5}{f^2}$ micro-inches, where f is the frequency in cycles per second.

[13]Note 13 was included in Part VI, page 17.

pleted structure to check the calculations and make minor readjustments.

In the case of small machinery, it is sometimes more economical to build a sample and measure the vibration than to spend too much time on laborious calculations. The vibration meter, therefore, is not a substitute for thorough theoretical analyses, but should be used to supplement and check such analyses. In many cases its use will greatly simplify the calculations and reduce the number which are necessary.

The vibration meter is also an invaluable tool in checking finished equipment for vibration and, indirectly, for noise, as previously pointed out in Part V. This last application allows noise tests to be carried on under unfavorable conditions of ambient noise level, after correlating noise meter and vibration tests on a few sample machines.

PART XII—ANALYSIS OF VIBRATION

The vibration meter measures the displacement, velocity, or acceleration of a vibration in terms of the r-m-s value of the waveform. Unless the waveform is substantially sinusoidal, however, the vibration meter by itself gives little information about the frequencies involved.[29] An analyzer, therefore, is desirable and in many cases a necessity. As with noise, the analysis of vibration provides clues to the sources of the various components and information necessary in the suppression of the vibration.

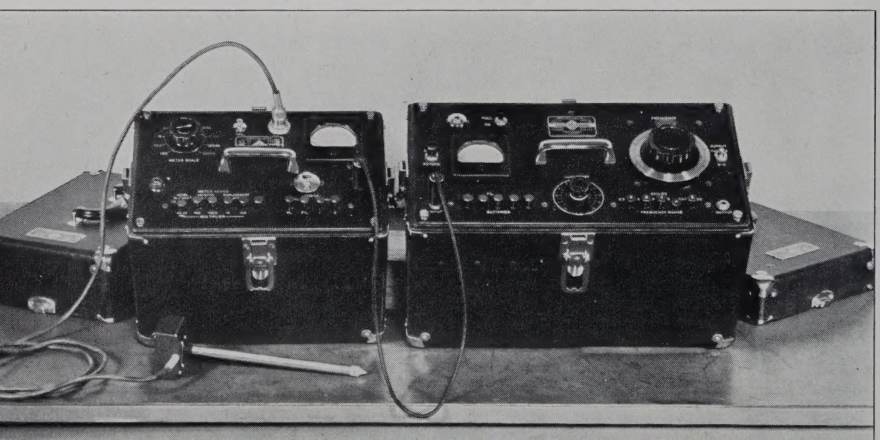
The general discussion of analysis and the classification of noises contained in Part VI applies equally well to vibration and need not be repeated here. Vibration, like noise, may be classified into two types — Class 1, or pitched, which consists mainly of harmonics or subharmonics of a fundamental frequency, all of which will vary in frequency by the same percentage that the machine speed varies; and Class 2, or unpitched, which are caused by shock excitation and occur over bands of frequencies.

Analyzer Characteristics

The degenerative analyzer circuit as used in the TYPE 760-B Sound Analyzer (see Part VI) is even better suited to vibration problems, since its circuit is naturally adapted for use at very low frequencies. This type of analyzer does not require any inductances or transformers in its construction. Hence it is free from the usual difficulties encoun-

[29]For sinusoidal vibrations, a measure of the frequency may be obtained by taking readings of displacement and velocity. As shown in Equations (5) and (6), the frequency will be: $f = \frac{v}{2\pi x}$. Displacement (x) and velocity (v) readings are better for this sort of frequency measurement than acceleration readings, since they are less affected by any harmonics that may be present in the waveform.

FIGURE 25. The TYPE 762-B Vibration Analyzer was designed particularly for use with the TYPE 761-A Vibration Meter.



tered when iron cores are used at low frequencies with attendant distortion and pickup. For use in the frequency range above 25 cycles, the standard TYPE 760-B Sound Analyzer is satisfactory. For vibration problems involving lower frequencies, a special instrument has been developed.

The Type 762-B Vibration Analyzer

The TYPE 762-B Vibration Analyzer[30] covers the frequency range from 2.5 to 750 cycles per second (150 to 45,000 rpm), but otherwise is similar to the sound analyzer. The meter scale on the vibration analyzer is calibrated in linear units for reading displacement, velocity, and acceleration directly in terms of micro-inches, micro-inches per second, and inches per second per second, respectively, rather than decibels, thus matching that on the TYPE 761-A Vibration Meter. The selectivity characteristics are shown in Figure 26. It will be noted that the selectivity curve maintains the important constant shape in terms of percentage of the resonant frequency over the entire range, while operation of a conventional heterodyne analyzer in the low-frequency range becomes completely impractical. The degenerative circuit, so far as is known at the present time, provides the most satisfactory means for obtaining high selectivity at sub-audible frequencies.

Two band widths are provided, selection being made by means of a panel switch. The BROAD SELECTIVITY position is extremely helpful in locating components quickly in a fast sweep over the spectrum, the final determination of frequency and amplitude being made with the SELECTIVITY switch in the SHARP position. It is also used in making the final determination of frequency and amplitude when the frequency of the component under measurement is drifting rapidly or is warbling about a mean frequency by several per cent.

The general design features of the vibration analyzer are the same as for the sound analyzer.

[30]This analyzer was described in "An Analyzer for Sub-Audible Frequencies" by H. H. Scott, Journal of the Acoustical Society of America, Vol. XIII, No. 4, pages 360–362, April, 1942. Also U. S. Patent No. 2,173,427.

PART XIII
HOW TO USE THE VIBRATION ANALYZER

Relative Readings

All batteries for operating the vibration analyzer are contained within the case. Push buttons and a neon lamp on the panel indicate when the batteries should be replaced. The instructions

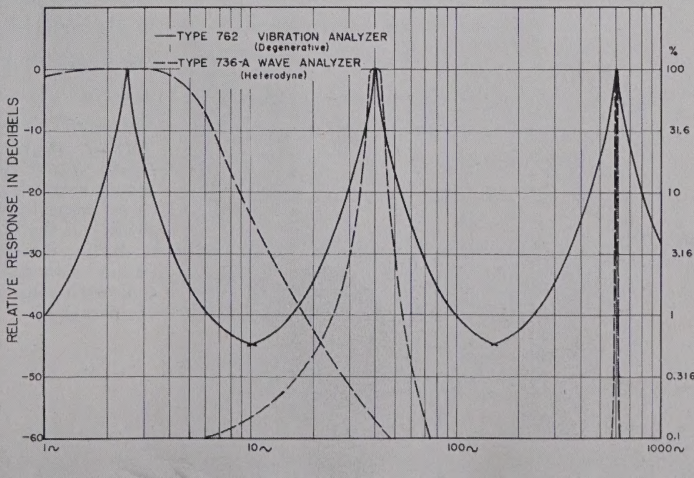
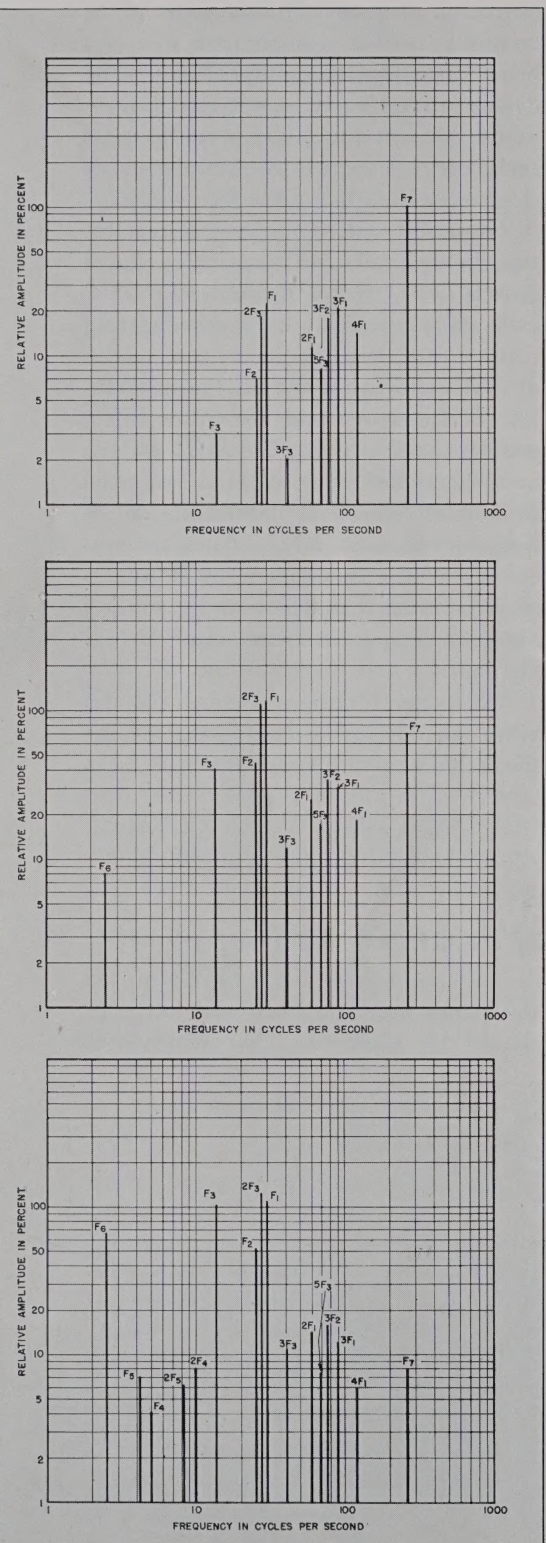


FIGURE 26. Selectivity characteristics of the TYPE 762-B Vibration Analyzer as compared with a typical (TYPE 736-A) heterodyne type of wave analyzer. Of utmost importance is the selectivity curve of the vibration analyzer, which maintains a satisfactory width and shape at both low and high vibration frequencies.



mounted in the cover of the instrument should be followed.

Tuning is accomplished by the large knob and the push button range switch. The calibration is direct reading in cycles per second and may be converted to rpm by multiplying by 60.

A cord is provided to connect the input of the analyzer to the output of the vibration meter. For relative readings, the 0-to-120 scale is most convenient, and the sensitivity control on the vibration analyzer should be set so that for the strongest component of the vibration the reading is 100. This should be done with the vibration meter so adjusted that a normal indication is obtained on the indicating meter of that instrument.

The best procedure for setting the sensitivity control of the analyzer is as follows: Press range button A (2.5 to 7.5 cycles) and turn the main analyzer dial slowly, noting the deflections of the meter on the analyzer. Repeat, covering the entire range of the instrument by successively pressing buttons B, C, D, and E, and turning the dial around. The dial may be rotated continuously in one direction.

During this process the SENSITIVITY control on the analyzer should be turned down whenever a component is found which deflects the meter above 100, so that the meter reads 100 exactly. This sets the sensitivity such that the analyzer will read 100% on the strongest component in the vibration. *Do not*

FIGURE 27. Typical analyses of machinery vibration, showing (top) acceleration, (center) velocity, and (bottom) displacement measurements as made on a single machine under the same conditions. These illustrate the complexity of the vibrations which can be analyzed with the vibration analyzer, also the differences in the importance of the various components in measurements of displacement, velocity, and acceleration.

change the setting of this control before the analysis is completed.

The analyzer should then be tuned for maximum amplitude on each component (without resetting the sensitivity control) and the results recorded directly in terms of frequency and percentage of the amplitude of the strongest component. The procedure is exactly the same as for the sound analyzer. Because of the natural slow response of highly selective low-frequency circuits, a METER RETURN button is provided. When the operator has tuned the analyzer away from a component, pressing this button will return the meter reading quickly to zero.

The vacuum-tube voltmeter circuit included in the vibration analyzer provides a semilogarithmic scale on the indicating meter, so that the entire usable range of the instrument may be obtained without additional multipliers, etc. The controls of the vibration meter and the SENSITIVITY control of the vibration analyzer should not be readjusted during the analysis.

The analyzer is equipped with an output jack for operating a pair of phones which may be used for listening to the component being measured, if it is of audible frequency.[31]

Absolute Readings

For most purposes, relative readings are sufficient, but absolute readings may also be made with the vibration analyzer if desired. For absolute readings, the calibration procedure is as follows: Connect the vibration meter to the 60-cycle line as when adjusting its calibration. Connect the analyzer to the vibration meter in the normal manner. Depress the button marked CALIBRATE 1 on the vibration meter and tune the analyzer to maximum response at the power-line frequency. Adjust the analyzer sensitivity control so that the meter on the analyzer reads the same as the one on the vibration meter.[32] It is desirable to mark this calibration point on the sensitivity dial of the analyzer with a pencil so that it can be returned to if the control is accidentally shifted. The control should be left at this point and not readjusted during an analysis.

After the analyzer sensitivity is set, the vibration meter should be disconnected from the power line and adjusted for normal reading on the vibration to be analyzed. The analyzer may then be tuned to the various components of the vibration, the meter of the analyzer being read in exactly the same way as the meter of the vibration meter, using the readings of the METER SCALE knob and the multiplier factors of the push buttons on the vibration meter. The METER SCALE knob on the vibration analyzer also should not be readjusted, but should be left at the setting which gives a deflection on the upper part of the meter scale on that instrument.

The red scale on the analyzer should be used when the METER SCALE

[31] Because of the a-v-c characteristics of the vacuum-tube voltmeter circuit, the output applied to the phones is not a pure sinusoid. Hence some output may be heard at very low frequencies which would normally be inaudible.

[32] On recent-production vibration analyzers the red and black scales track the same as on the vibration meter. On earlier models the scales are slightly displaced. With these analyzers two positions of the sensitivity control should be determined, one for the red scale and one for the black, if maximum possible accuracy is desirable. Otherwise an average setting is satisfactory.

[33] Referring to Note 21, page 29, which gives general equations for Class 1 (pitched) vibrations, the readings of the analyzer on displacement will correspond to $\frac{1}{\sqrt{2}}A_1, \frac{1}{\sqrt{2}}A_2, \frac{1}{\sqrt{2}}A_3$, etc., on velocity to $\frac{1}{\sqrt{2}}\omega_1 A_1, \frac{1}{\sqrt{2}}2\omega_1 A_2, \frac{1}{\sqrt{2}}3\omega_1 A_3$, etc., and on acceleration to $\frac{1}{\sqrt{2}}\omega^2_1 A_1, \frac{1}{\sqrt{2}}4\omega^2_1 A_2, \frac{1}{\sqrt{2}}9\omega^2_1 A_3$, etc. The corresponding total levels indicated by the vibration meter are given in Note 22. In general, the equations for Class 2 (unpitched) vibrations will be the same, excepting that the components are not necessarily harmonically related.

knob of the vibration meter is set at a red point and the black scale when the knob is set at an uncolored point. The analysis will then be in terms of the same absolute values as the vibration meter reading[33] and the same multiplying factors will apply.

Displacement, Velocity, and Acceleration

The analysis will be made in terms of displacement, velocity, or acceleration, depending upon the setting of the vibration meter. Choice among these different characteristics should be based upon the same considerations as when measuring vibration, as described in Part XI.

Figure 27 shows typical machinery vibration analyses as made with the TYPE 761-A Vibration Meter and the TYPE 762-B Vibration Analyzer for (a) displacement, (b) velocity, and (c) acceleration. The change in the relative amplitudes of the various components for the different types of measurements will be noted.

The use of the TYPE 762-B Vibration Analyzer is not limited to the analysis of the output of the TYPE 761-A Vibration Meter. It can be used with practically any vibration meter for analyzing either linear or torsional vibrations.

DECIBEL CONVERSION TABLES

It is convenient in measurements and calculations on communications systems to express the ratio between any two amounts of electric or acoustic power in units on a logarithmic scale. The *decibel* (1/10th of the *bel*) on the briggsian or base-10 scale is in almost universal use for this purpose.

Table I and Table II on the following pages have been prepared to facilitate making conversions in either direction between the number of *decibels* and the corresponding power and pressure ratios.

Decibel — The number of decibels N_{db} corresponding to the ratio between two amounts of power P_1 and P_2 is

$$N_{db} = 10 \log_{10} \frac{P_1}{P_2} \qquad (1)$$

When two pressures E_1 and E_2 operate in the same or equal impedances,

$$N_{db} = 20 \log_{10} \frac{E_1}{E_2} \qquad (2)$$

TO FIND VALUES OUTSIDE THE RANGE OF CONVERSION TABLES

Values outside the range of either Table I or Table II on the following pages can be readily found with the help of the following simple rules:

TABLE I: DECIBELS TO PRESSURE AND POWER RATIOS

Number of decibels positive (+): Subtract +20 decibels successively from the given number of decibels until the remainder falls within range of Table I. *To find the pressure ratio,* multiply the corresponding value from the right-hand voltage-ratio column by 10 for each time you subtracted 20 db. *To find the power ratio,* multiply the corresponding value from the right-hand power-ratio column by 100 for each time you subtracted 20 db.

Example — *Given:* 49.2 db

49.2 db − 20 db − 20 db = 9.2 db

Pressure ratio: 9.2 db →

2.884 × 10 × 10 = 288.4

Power ratio: 9.2 db →

8.318 × 100 × 100 = 83180

Number of decibels negative (−): Add +20 decibels successively to the given number of decibels until the sum falls within the range of Table I. *For the pressure ratio,* divide the value from the left-hand pressure-ratio column by 10 for each time you added 20 db. *For the power ratio,* divide the value from the left-hand power-ratio column by 100 for each time you added 20 db.

Example — *Given:* −49.2 db

−49.2 db + 20 db + 20 db = −9.2 db

Pressure ratio: −9.2 db →

.3467 × 1/10 × 1/10 = .003467

Power ratio: −9.2 db →

.1202 × 1/100 × 1/100 = .00001202

TABLE II: PRESSURE RATIOS TO DECIBELS

For ratios smaller than those in table — Multiply the given ratio by 10 successively until the product can be found in the table. From the number of decibels thus found, subtract +20 decibels for each time you multiplied by 10.

Example—*Given:* Pressure ratio = .0131

.0131 × 10 × 10 = 1.31

From Table II, 1.31 →

2.345 db − 20 db − 20 db = −37.655 db

For ratios greater than those in table — Divide the given ratio by 10 successively until the remainder can be found in the table. To the number of decibels thus found, add +20 db for each time you divided by 10.

Example—*Given:* Pressure ratio = 712

712 × 1/10 × 1/10 = 7.12

From Table II, 7.12 →

17.050 db + 20 db + 20 db = 57.050 db

TABLE I

GIVEN: Decibels — TO FIND: Power and Pressure Ratios

TO ACCOUNT FOR THE SIGN OF THE DECIBEL

For positive (+) values of the decibel— Both pressure and power ratios are greater than unity. Use the two right-hand columns.

For negative (—) values of the decibel—Both pressure and power ratios are less than unity. Use the two left-hand columns.

Example—*Given:* ± 9.1 db. *Find:*

	Power Ratio	*Pressure Ratio*
+9.1 db	8.128	2.851
—9.1 db	0.1230	0.3508

← −db			+db →	
Pressure Ratio	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*
1.0000	**1.0000**	**0**	**1.000**	**1.000**
.9886	.9772	.1	1.012	1.023
.9772	.9550	.2	1.023	1.047
.9661	.9333	.3	1.035	1.072
.9550	.9120	.4	1.047	1.096
.9441	.8913	.5	1.059	1.122
.9333	.8710	.6	1.072	1.148
.9226	.8511	.7	1.084	1.175
.9120	.8318	.8	1.096	1.202
.9016	.8128	.9	1.109	1.230
.8913	**.7943**	**1.0**	**1.122**	**1.259**
.8810	.7762	1.1	1.135	1.288
.8710	.7586	1.2	1.148	1.318
.8610	.7413	1.3	1.161	1.349
.8511	.7244	1.4	1.175	1.380
.8414	.7079	1.5	1.189	1.413
.8318	.6918	1.6	1.202	1.445
.8222	.6761	1.7	1.216	1.479
.8128	.6607	1.8	1.230	1.514
.8035	.6457	1.9	1.245	1.549
.7943	**.6310**	**2.0**	**1.259**	**1.585**
.7852	.6166	2.1	1.274	1.622
.7762	.6026	2.2	1.288	1.660
.7674	.5888	2.3	1.303	1.698
.7586	.5754	2.4	1.318	1.738
.7499	.5623	2.5	1.334	1.778
.7413	.5495	2.6	1.349	1.820
.7328	.5370	2.7	1.365	1.862
.7244	.5248	2.8	1.380	1.905
.7161	.5129	2.9	1.396	1.950
.7079	**.5012**	**3.0**	**1.413**	**1.995**
.6998	.4898	3.1	1.429	2.042
.6918	.4786	3.2	1.445	2.089
.6839	.4677	3.3	1.462	2.138
.6761	.4571	3.4	1.479	2.188
.6683	.4467	3.5	1.496	2.239
.6607	.4365	3.6	1.514	2.291
.6531	.4266	3.7	1.531	2.344
.6457	.4169	3.8	1.549	2.399
.6383	.4074	3.9	1.567	2.455
.6310	**.3981**	**4.0**	**1.585**	**2.512**
.6237	.3890	4.1	1.603	2.570
.6166	.3802	4.2	1.622	2.630
.6095	.3715	4.3	1.641	2.692
.6026	.3631	4.4	1.660	2.754
.5957	.3548	4.5	1.679	2.818
.5888	.3467	4.6	1.698	2.884
.5821	.3388	4.7	1.718	2.951
.5754	.3311	4.8	1.738	3.020
.5689	.3236	4.9	1.758	3.090

← −db			+db →	
Pressure Ratio	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*
.5623	**.3162**	**5.0**	**1.778**	**3.162**
.5559	.3090	5.1	1.799	3.236
.5495	.3020	5.2	1.820	3.311
.5433	.2951	5.3	1.841	3.388
.5370	.2884	5.4	1.862	3.467
.5309	.2818	5.5	1.884	3.548
.5248	.2754	5.6	1.905	3.631
.5188	.2692	5.7	1.928	3.715
.5129	.2630	5.8	1.950	3.802
.5070	.2570	5.9	1.972	3.890
.5012	**.2512**	**6.0**	**1.995**	**3.981**
.4955	.2455	6.1	2.018	4.074
.4898	.2399	6.2	2.042	4.169
.4842	.2344	6.3	2.065	4.266
.4786	.2291	6.4	2.089	4.365
.4732	.2239	6.5	2.113	4.467
.4677	.2188	6.6	2.138	4.571
.4624	.2138	6.7	2.163	4.677
.4571	.2089	6.8	2.188	4.786
.4519	.2042	6.9	2.213	4.898
.4467	**.1995**	**7.0**	**2.239**	**5.012**
.4416	.1950	7.1	2.265	5.129
.4365	.1905	7.2	2.291	5.248
.4315	.1862	7.3	2.317	5.370
.4266	.1820	7.4	2.344	5.495
.4217	.1778	7.5	2.371	5.623
.4169	.1738	7.6	2.399	5.754
.4121	.1698	7.7	2.427	5.888
.4074	.1660	7.8	2.455	6.026
.4027	.1622	7.9	2.483	6.166
.3981	**.1585**	**8.0**	**2.512**	**6.310**
.3936	.1549	8.1	2.541	6.457
.3890	.1514	8.2	2.570	6.607
.3846	.1479	8.3	2.600	6.761
.3802	.1445	8.4	2.630	6.918
.3758	.1413	8.5	2.661	7.079
.3715	.1380	8.6	2.692	7.244
.3673	.1349	8.7	2.723	7.413
.3631	.1318	8.8	2.754	7.586
.3589	.1288	8.9	2.786	7.762
.3548	**.1259**	**9.0**	**2.818**	**7.943**
.3508	.1230	9.1	2.851	8.128
.3467	.1202	9.2	2.884	8.318
.3428	.1175	9.3	2.917	8.511
.3388	.1148	9.4	2.951	8.710
.3350	.1122	9.5	2.985	8.913
.3311	.1096	9.6	3.020	9.120
.3273	.1072	9.7	3.055	9.333
.3236	.1047	9.8	3.090	9.550
.3199	.1023	9.9	3.126	9.772

TABLE I (continued)

←−db+→				
Pressure Ratio	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*
.3162	.1000	10.0	3.162	10.000
.3126	.09772	10.1	3.199	10.23
.3090	.09550	10.2	3.236	10.47
.3055	.09333	10.3	3.273	10.72
.3020	.09120	10.4	3.311	10.96
.2985	.08913	10.5	3.350	11.22
.2951	.08710	10.6	3.388	11.48
.2917	.08511	10.7	3.428	11.75
.2884	.08318	10.8	3.467	12.02
.2851	.08128	10.9	3.508	12.30
.2818	.07943	11.0	3.548	12.59
.2786	.07762	11.1	3.589	12.88
.2754	.07586	11.2	3.631	13.18
.2723	.07413	11.3	3.673	13.49
.2692	.07244	11.4	3.715	13.80
.2661	.07079	11.5	3.758	14.13
.2630	.06918	11.6	3.802	14.45
.2600	.06761	11.7	3.846	14.79
.2570	.06607	11.8	3.890	15.14
.2541	.06457	11.9	3.936	15.49
.2512	.06310	12.0	3.981	15.85
.2483	.06166	12.1	4.027	16.22
.2455	.06026	12.2	4.074	16.60
.2427	.05888	12.3	4.121	16.98
.2399	.05754	12.4	4.169	17.38
.2371	.05623	12.5	4.217	17.78
.2344	.05495	12.6	4.266	18.20
.2317	.05370	12.7	4.315	18.62
.2291	.05248	12.8	4.365	19.05
.2265	.05129	12.9	4.416	19.50
.2239	.05012	13.0	4.467	19.95
.2213	.04898	13.1	4.519	20.42
.2188	.04786	13.2	4.571	20.89
.2163	.04677	13.3	4.624	21.38
.2138	.04571	13.4	4.677	21.88
.2113	.04467	13.5	4.732	22.39
.2089	.04365	13.6	4.786	22.91
.2065	.04266	13.7	4.842	23.44
.2042	.04169	13.8	4.898	23.99
.2018	.04074	13.9	4.955	24.55
.1995	.03981	14.0	5.012	25.12
.1972	.03890	14.1	5.070	25.70
.1950	.03802	14.2	5.129	26.30
.1928	.03715	14.3	5.188	26.92
.1905	.03631	14.4	5.248	27.54
.1884	.03548	14.5	5.309	28.18
.1862	.03467	14.6	5.370	28.84
.1841	.03388	14.7	5.433	29.51
.1820	.03311	14.8	5.495	30.20
.1799	.03236	14.9	5.559	30.90
.1778	.03162	15.0	5.623	31.62
.1758	.03090	15.1	5.689	32.36
.1738	.03020	15.2	5.754	33.11
.1718	.02951	15.3	5.821	33.88
.1698	.02884	15.4	5.888	34.67
.1679	.02818	15.5	5.957	35.48
.1660	.02754	15.6	6.026	36.31
.1641	.02692	15.7	6.095	37.15
.1622	.02630	15.8	6.166	38.02
.1603	.02570	15.9	6.237	38.90

←−db+→				
Pressure Ratio	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*
.1585	.02512	16.0	6.310	39.81
.1567	.02455	16.1	6.383	40.74
.1549	.02399	16.2	6.457	41.69
.1531	.02344	16.3	6.531	42.66
.1514	.02291	16.4	6.607	43.65
.1496	.02239	16.5	6.683	44.67
.1479	.02188	16.6	6.761	45.71
.1462	.02138	16.7	6.839	46.77
.1445	.02089	16.8	6.918	47.86
.1429	.02042	16.9	6.998	48.98
.1413	.01995	17.0	7.079	50.12
.1396	.01950	17.1	7.161	51.29
.1380	.01905	17.2	7.244	52.48
.1365	.01862	17.3	7.328	53.70
.1349	.01820	17.4	7.413	54.95
.1334	.01778	17.5	7.499	56.23
.1318	.01738	17.6	7.586	57.54
.1303	.01698	17.7	7.674	58.88
.1288	.01660	17.8	7.762	60.26
.1274	.01622	17.9	7.852	61.66
.1259	.01585	18.0	7.943	63.10
.1245	.01549	18.1	8.035	64.57
.1230	.01514	18.2	8.128	66.07
.1216	.01479	18.3	8.222	67.61
.1202	.01445	18.4	8.318	69.18
.1189	.01413	18.5	8.414	70.79
.1175	.01380	18.6	8.511	72.44
.1161	.01349	18.7	8.610	74.13
.1148	.01318	18.8	8.710	75.86
.1135	.01288	18.9	8.811	77.62
.1122	.01259	19.0	8.913	79.43
.1109	.01230	19.1	9.016	81.28
.1096	.01202	19.2	9.120	83.18
.1084	.01175	19.3	9.226	85.11
.1072	.01148	19.4	9.333	87.10
.1059	.01122	19.5	9.441	89.13
.1047	.01096	19.6	9.550	91.20
.1035	.01072	19.7	9.661	93.33
.1023	.01047	19.8	9.772	95.50
.1012	.01023	19.9	9.886	97.72
.1000	.01000	20.0	10.000	100.00

←−db+→				
Pressure Ratio	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*
3.162×10^{-1}	10^{-1}	10	3.162	10
10^{-1}	10^{-2}	20	10	10^{2}
3.162×10^{-2}	10^{-3}	30	3.162×10	10^{3}
10^{-2}	10^{-4}	40	10^{2}	10^{4}
3.162×10^{-3}	10^{-5}	50	3.162×10^{2}	10^{5}
10^{-3}	10^{-6}	60	10^{3}	10^{6}
3.162×10^{-4}	10^{-7}	70	3.162×10^{3}	10^{7}
10^{-4}	10^{-8}	80	10^{4}	10^{8}
3.162×10^{-5}	10^{-9}	90	3.162×10^{4}	10^{9}
10^{-5}	10^{-10}	100	10^{5}	10^{10}

To find decibel values outside the range of this table, see page 38

TABLE II

GIVEN: { Pressure } Ratio TO FIND: Decibels

POWER RATIOS

To find the number of decibels corresponding to a given power ratio—Assume the given power ratio to be a pressure ratio and find the corresponding number of decibels from the table. The desired result is exactly one-half of the number of decibels thus found.

Example—*Given:* a power ratio of 3.41. *Find:* 3.41 in the table:

$3.41 \rightarrow 10.655 \text{ db} \times \frac{1}{2} = 5.328 \text{ db}$

Pressure Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	**.000**	**.086**	**.172**	**.257**	**.341**	**.424**	**.506**	**.588**	**.668**	**.749**
1.1	.828	.906	.984	1.062	1.138	1.214	1.289	1.364	1.438	1.511
1.2	1.584	1.656	1.727	1.798	1.868	1.938	2.007	2.076	2.144	2.212
1.3	2.279	2.345	2.411	2.477	2.542	2.607	2.671	2.734	2.798	2.860
1.4	2.923	2.984	3.046	3.107	3.167	3.227	3.287	3.346	3.405	3.464
1.5	3.522	3.580	3.637	3.694	3.750	3.807	3.862	3.918	3.973	4.028
1.6	4.082	4.137	4.190	4.244	4.297	4.350	4.402	4.454	4.506	4.558
1.7	4.609	4.660	4.711	4.761	4.811	4.861	4.910	4.959	5.008	5.057
1.8	5.105	5.154	5.201	5.249	5.296	5.343	5.390	5.437	5.483	5.529
1.9	5.575	5.621	5.666	5.711	5.756	5.801	5.845	5.889	5.933	5.977
2.0	**6.021**	**6.064**	**6.107**	**6.150**	**6.193**	**6.235**	**6.277**	**6.319**	**6.361**	**6.403**
2.1	6.444	6.486	6.527	6.568	6.608	6.649	6.689	6.729	6.769	6.809
2.2	6.848	6.888	6.927	6.966	7.008	7.044	7.082	7.121	7.159	7.197
2.3	7.235	7.272	7.310	7.347	7.384	7.421	7.458	7.495	7.532	7.568
2.4	7.604	7.640	7.676	7.712	7.748	7.783	7.819	7.854	7.889	7.924
2.5	7.959	7.993	8.028	8.062	8.097	8.131	8.165	8.199	8.232	8.266
2.6	8.299	8.333	8.366	8.399	8.432	8.465	8.498	8.530	8.563	8.595
2.7	8.627	8.659	8.691	8.723	8.755	8.787	8.818	8.850	8.881	8.912
2.8	8.943	8.974	9.005	9.036	9.066	9.097	9.127	9.158	9.188	9.218
2.9	9.248	9.278	9.308	9.337	9.367	9.396	9.426	9.455	9.484	9.513
3.0	**9.542**	**9.571**	**9.600**	**9.629**	**9.657**	**9.686**	**9.714**	**9.743**	**9.771**	**9.799**
3.1	9.827	9.855	9.883	9.911	9.939	9.966	9.994	10.021	10.049	10.076
3.2	10.103	10.130	10.157	10.184	10.211	10.238	10.264	10.291	10.317	10.344
3.3	10.370	10.397	10.423	10.449	10.475	10.501	10.527	10.553	10.578	10.604
3.4	10.630	10.655	10.681	10.706	10.731	10.756	10.782	10.807	10.832	10.857
3.5	10.881	10.906	10.931	10.955	10.980	11.005	11.029	11.053	11.078	11.102
3.6	11.126	11.150	11.174	11.198	11.222	11.246	11.270	11.293	11.317	11.341
3.7	11.364	11.387	11.411	11.434	11.457	11.481	11.504	11.527	11.550	11.573
3.8	11.596	11.618	11.641	11.664	11.687	11.709	11.732	11.754	11.777	11.799
3.9	11.821	11.844	11.866	11.888	11.910	11.932	11.954	11.976	11.998	12.019
4.0	**12.041**	**12.063**	**12.085**	**12.106**	**12.128**	**12.149**	**12.171**	**12.192**	**12.213**	**12.234**
4.1	12.256	12.277	12.298	12.319	12.340	12.361	12.382	12.403	12.424	12.444
4.2	12.465	12.486	12.506	12.527	12.547	12.568	12.588	12.609	12.629	12.649
4.3	12.669	12.690	12.710	12.730	12.750	12.770	12.790	12.810	12.829	12.849
4.4	12.869	12.889	12.908	12.928	12.948	12.967	12.987	13.006	13.026	13.045
4.5	13.064	13.084	13.103	13.122	13.141	13.160	13.179	13.198	13.217	13.236
4.6	13.255	13.274	13.293	13.312	13.330	13.349	13.368	13.386	13.405	13.423
4.7	13.442	13.460	13.479	13.497	13.516	13.534	13.552	13.570	13.589	13.607
4.8	13.625	13.643	13.661	13.679	13.697	13.715	13.733	13.751	13.768	13.786
4.9	13.804	13.822	13.839	13.857	13.875	13.892	13.910	13.927	13.945	13.962
5.0	**13.979**	**13.997**	**14.014**	**14.031**	**14.049**	**14.066**	**14.083**	**14.100**	**14.117**	**14.134**
5.1	14.151	14.168	14.185	14.202	14.219	14.236	14.253	14.270	14.287	14.303
5.2	14.320	14.337	14.353	14.370	14.387	14.403	14.420	14.436	14.453	14.469
5.3	14.486	14.502	14.518	14.535	14.551	14.567	14.583	14.599	14.616	14.632
5.4	14.648	14.664	14.680	14.696	14.712	14.728	14.744	14.760	14.776	14.791
5.5	14.807	14.823	14.839	14.855	14.870	14.886	14.902	14.917	14.933	14.948
5.6	14.964	14.979	14.995	15.010	15.026	15.041	15.056	15.072	15.087	15.102
5.7	15.117	15.133	15.148	15.163	15.178	15.193	15.208	15.224	15.239	15.254
5.8	15.269	15.284	15.298	15.313	15.328	15.343	15.358	15.373	15.388	15.402
5.9	15.417	15.432	15.446	15.461	15.476	15.490	15.505	15.519	15.534	15.549

TABLE II (continued)

Pressure Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
6.0	**15.563**	**15.577**	**15.592**	**15.606**	**15.621**	**15.635**	**15.649**	**15.664**	**15.678**	**15.692**
6.1	15.707	15.721	15.735	15.749	15.763	15.778	15.792	15.806	15.820	15.834
6.2	15.848	15.862	15.876	15.890	15.904	15.918	15.931	15.945	15.959	15.973
6.3	15.987	16.001	16.014	16.028	16.042	16.055	16.069	16.083	16.096	16.110
6.4	16.124	16.137	16.151	16.164	16.178	16.191	16.205	16.218	16.232	16.245
6.5	16.258	16.272	16.285	16.298	16.312	16.325	16.338	16.351	16.365	16.378
6.6	16.391	16.404	16.417	16.430	16.443	16.456	16.469	16.483	16.496	16.509
6.7	16.521	16.534	16.547	16.560	16.573	16.586	16.599	16.612	16.625	16.637
6.8	16.650	16.663	16.676	16.688	16.701	16.714	16.726	16.739	16.752	16.764
6.9	16.777	16.790	16.802	16.815	16.827	16.840	16.852	16.865	16.877	16.890
7.0	**16.902**	**16.914**	**16.927**	**16.939**	**16.951**	**16.964**	**16.976**	**16.988**	**17.001**	**17.013**
7.1	17.025	17.037	17.050	17.062	17.074	17.086	17.098	17.110	17.122	17.135
7.2	17.147	17.159	17.171	17.183	17.195	17.207	17.219	17.231	17.243	17.255
7.3	17.266	17.278	17.290	17.302	17.314	17.326	17.338	17.349	17.361	17.373
7.4	17.385	17.396	17.408	17.420	17.431	17.443	17.455	17.466	17.478	17.490
7.5	17.501	17.513	17.524	17.536	17.547	17.559	17.570	17.582	17.593	17.605
7.6	17.616	17.628	17.639	17.650	17.662	17.673	17.685	17.696	17.707	17.719
7.7	17.730	17.741	17.752	17.764	17.775	17.786	17.797	17.808	17.820	17.831
7.8	17.842	17.853	17.864	17.875	17.886	17.897	17.908	17.919	17.931	17.942
7.9	17.953	17.964	17.975	17.985	17.996	18.007	18.018	18.029	18.040	18.051
8.0	**18.062**	**18.073**	**18.083**	**18.094**	**18.105**	**18.116**	**18.127**	**18.137**	**18.148**	**18.159**
8.1	18.170	18.180	18.191	18.202	18.212	18.223	18.234	18.244	18.255	18.266
8.2	18.276	18.287	18.297	18.308	18.319	18.329	18.340	18.350	18.361	18.371
8.3	18.382	18.392	18.402	18.413	18.423	18.434	18.444	18.455	18.465	18.475
8.4	18.486	18.496	18.506	18.517	18.527	18.537	18.547	18.558	18.568	18.578
8.5	18.588	18.599	18.609	18.619	18.629	18.639	18.649	18.660	18.670	18.680
8.6	18.690	18.700	18.710	18.720	18.730	18.740	18.750	18.760	18.770	18.780
8.7	18.790	18.800	18.810	18.820	18.830	18.840	18.850	18.860	18.870	18.880
8.8	18.890	18.900	18.909	18.919	18.929	18.939	18.949	18.958	18.968	18.978
8.9	18.988	18.998	19.007	19.017	19.027	19.036	19.046	19.056	19.066	19.075
9.0	**19.085**	**19.094**	**19.104**	**19.114**	**19.123**	**19.133**	**19.143**	**19.152**	**19.162**	**19.171**
9.1	19.181	19.190	19.200	19.209	19.219	19.228	19.238	19.247	19.257	19.266
9.2	19.276	19.285	19.295	19.304	19.313	19.323	19.332	19.342	19.351	19.360
9.3	19.370	19.379	19.388	19.398	19.407	19.416	19.426	19.435	19.444	19.453
9.4	19.463	19.472	19.481	19.490	19.499	19.509	19.518	19.527	19.536	19.545
9.5	19.554	19.564	19.573	19.582	19.591	19.600	19.609	19.618	19.627	19.636
9.6	19.645	19.654	19.664	19.673	19.682	19.691	19.700	19.709	19.718	19.726
9.7	19.735	19.744	19.753	19.762	19.771	19.780	19.789	19.798	19.807	19.816
9.8	19.825	19.833	19.842	19.851	19.860	19.869	19.878	19.886	19.895	19.904
9.9	19.913	19.921	19.930	19.939	19.948	19.956	19.965	19.974	19.983	19.991

Pressure Ratio	0	1	2	3	4	5	6	7	8	9
10	**20.000**	**20.828**	**21.584**	**22.279**	**22.923**	**23.522**	**24.082**	**24.609**	**25.105**	**25.575**
20	26.021	26.444	26.848	27.235	27.604	27.959	28.299	28.627	28.943	29.248
30	29.542	29.827	30.103	30.370	30.630	30.881	31.126	31.364	31.596	31.821
40	32.041	32.256	32.465	32.669	32.869	33.064	33.255	33.442	33.625	33.804
50	33.979	34.151	34.320	34.486	34.648	34.807	34.964	35.117	35.269	35.417
60	35.563	35.707	35.848	35.987	36.124	36.258	36.391	36.521	36.650	36.777
70	36.902	37.025	37.147	37.266	37.385	37.501	37.616	37.730	37.842	37.953
80	38.062	38.170	38.276	38.382	38.486	38.588	38.690	38.790	38.890	38.988
90	39.085	39.181	39.276	39.370	39.463	39.554	39.645	39.735	39.825	39.913
100	**40.000**	—	—	—	—	—	—	—	—	—

To find ratios outside the range of this table, see page 38

TYPE 759-B

SOUND-LEVEL

METER

Uses: The TYPE 759-B Sound-Level Meter is suitable for all types of commercial and industrial noise measurement. Manufacturers of machinery and appliances use it for measuring product noise both in the research laboratory and in production. Sound transmission and absorption and the acoustical properties of materials can also be measured with it. It meets equally well the requirements for noise measurement in surveys of the psychological and physiological effects of noise.

For the industrial plant, it provides a means of measuring product noise, setting up noise standards, accepting or rejecting products on the basis of noise tests, and, finally, analyzing and correcting trouble in the rejected units.

In this last use, as in many others, a frequency analysis of the noise is usually valuable. For this purpose, the TYPE 760-B Sound Analyzer (see page 48) has been designed.

The usefulness of the sound-level meter may be extended to include vibration measurements by substituting a vibration pickup (see page 47) for the microphone. The low-frequency response of the sound-level meter is sufficiently good to permit vibration measurements at frequencies down to 20 cycles. Such measurements include the fundamental and harmonic frequency vibrations of machines rotating at 1200 rpm or higher, as well as many structural resonances.

For vibration measurements below 20 cycles, however, the TYPE 761-A Vibration Meter is recommended (see page 51).

Description: TYPE 759-B Sound-Level Meter is an accurate, portable, low-priced meter for reading, in terms of a standard reference level, the sound level at its microphone.

The sound-level meter consists of a non-directional microphone, an amplifier, a calibrated attenuator, and an indicating meter. It is battery operated and completely self-contained.

An a-c power supply unit is also available (see page 46).

This sound-level meter complies with all the tentative standards for sound-

level meters specified by the American Standards Association, the American Institute of Electrical Engineers, and the Acoustical Society of America.

All three frequency response characteristics recommended by the A.S.A. are included. In addition to the standard meter characteristic, a heavily damped movement, for reading rapidly fluctuating sounds, is provided.

Features: The outstanding features of this instrument are its portability and ease of operation. Weighing a little over 20 pounds, and being completely self-contained (including the batteries or a-c power supply), the instrument is completely portable. It is so simple in operation that it can be used by non-technical personnel.

SPECIFICATIONS

Sound-Level Range: Calibrated in decibels from +24 db to 140 db above the standard reference sound pressure of 0.0002 dynes per square centimeter (an intensity level of 10^{-16} watts per square centimeter for a free, progressive wave in air at standard temperature and pressure) at 1000 cycles.

Frequency Characteristics: The frequency characteristic of the sound-level meter is adjustable to follow three different curves. The first and second of these are, respectively, the 40 and 70 db equal-loudness contours in accordance with the tentative standard proposed by the American Standards Association. The third frequency response characteristic gives a substantially equal response to all frequencies within the range of the instrument. This characteristic is used when measuring extremely high sound levels or when using the instrument with TYPE 760-B Sound Analyzer.

Microphone: The microphone mounts on a folding bracket on top of the instrument and folds down into a recess in the panel when not in use. It can be removed from its mounting bracket for use with an extension cable and tripod (see price list).

The microphone is of the crystal, diaphragm type with an essentially non-directional response characteristic. It is rugged and stable, and its sensitivity is substantially unaffected by ordinary changes in temperature and humidity.

The response of the microphone is essentially flat below 4000 cycles, and the absolute level (of the sound-level meter) is corrected in accordance with the ASA tentative standards to cancel out any minor microphone irregularities when sounds of average frequency distribution are being measured.

The absolute level of all microphones is checked at several frequencies against a standard microphone, whose calibration is periodically checked by the U.S. Bureau of Standards. In addition the impedance of the microphone is held to close tolerances.

Vibration Pickup: The TYPE 759-P35 Vibration Pickup with the TYPE 759-P36 Control Box can be used in place of the microphone (see page 47).

Meter plus Attenuator: The sound level is read as the sum of the meter reading and the reading of a stepped attenuator. A single knob controls two attenuators furnishing a total of 100 db attenuation in steps of 10 db. The indicating meter is approximately linear in decibels, and its scale is open and easily read. It covers a 16 db range, thus providing a satisfactory overlap between the steps of the attenuator. A SLOW-FAST switch makes available two meter speeds. With the control switch in the FAST position the ballistic characteristics of the meter closely match those of the human ear and agree with tentative standards of the American Standards Association. In the SLOW position the meter is shunted by a large condenser. The resulting heavily damped movement is convenient for observing the average level of rapidly fluctuating sounds.

Calibration: A means is provided for standardizing the sensitivity of the instrument. Any a-c power line of approximately 115 volts can be used as a source of standardizing voltage. A seven-foot line-connector cord is furnished for this purpose and is stored in the cover of the carrying case.

Accuracy: The frequency response curves of the TYPE 759-B Sound-Level Meter fall within the tolerances specified by the ASA tentative standards. When the amplifier sensitivity is standardized the absolute accuracy of sound-level measurements is within ±1 decibel for average machinery noises in accordance with the ASA standards.

Temperature and Humidity Effects: Readings are independent (within 1 db) of temperature and humidity over the ranges of room conditions normally encountered.

Extension Cable and Tripod: An extension cable and tripod (TYPE 759-P21) can be supplied for using the microphone at a distance from the sound-level meter. A correction curve is supplied, giving the cable correction as a function of temperature. This temperature correction is of importance only above 85° Fahrenheit.

Batteries: A single block battery (Burgess type 6TA60) is used and one is supplied with the instrument. The TYPE 1261-A Power Supply is available if a-c operation is desired (see below).

Tubes: Three type 1N5-GT and one type 1D8-GT are required. A complete set is supplied with the instrument.

Case: The sound-level meter is mounted in a shielded carrying case of durable airplane luggage construction.

Dimensions: The over-all dimensions are approximately: (height) 11½ x (length) 13½ x (width) 9½ inches.

Net Weight: 22¼ pounds with battery; 17¼ pounds, without battery.

Type		*Code Word*	*Price*
759-B	**Sound-Level Meter**	NOMAD	$350.00
	Replacement Battery for above	NOMADNUBAT	5.50
759-P21	**Extension Cable (25 ft.) and Tripod**	KIMBO	18.50

(Licensed under patents of the American Telephone and Telegraph Company)

TYPE 1261-A POWER SUPPLY

Uses: The TYPE 1261-A Power Supply is an a-c power pack for use in place of batteries in the TYPE 759-B Sound-Level Meter. The power pack is designed to be the equivalent of a BA48 combination battery in voltages, current, size, and shape, so that it is interchangeable electrically and mechanically with the battery.

Description: This power supply is a light, compact unit that fits into the battery compartment of General Radio instruments which use the BA48 battery block.

A selenium rectifier and L-C filter with two flashlight cells floating across the output provide a low-impedance, well-filtered, and regulated d-c filament supply. A conventional vacuum-tube rectifier and R-C filter provide the plate supply. A four-terminal output socket fits the plug on the battery cable of the sound-level meter.

Features: The two flashlight cells which are floated across the output of the filament supply not only function well as a large filtering condenser, but they have the additional feature that they maintain essentially constant filament voltage. A small push button switch mounted on top of the power supply makes it possible to disconnect the cells at any time and set the output voltage equal to the cell voltage. When the power supply is in operation, normal line voltage variations cause the cells to either charge slightly or deliver small amounts of power to the load. When the instrument is turned off, a small relay, built as part of one of the filter chokes, opens the circuit so that the cells will not run down. The life of the cells is practically equal to their normal shelf life.

SPECIFICATIONS

Input Voltage: 105–125 volts, 40 to 60 cycles.

Input Power: Less than 8 watts at 115 volts, 60 cycles.

Tube: One TYPE 6H6 is supplied.

Batteries: Two Burgess No. 2 uni-cells, which are floated across the output of the Filament Supply, are furnished.

Terminals: A four-terminal output socket fits the plug on the battery cable of the TYPE 759-B.

Dimensions: (Length) 10 x (width) 2¼ x (depth) 5 inches.

Net Weight: 7¼ pounds (less power cord).

Type		*Code Word*	*Price*
1261-A	**Power Supply**	NUTTY	$120.00

When ordering, specify TYPE 1261-P2 Selector Plug desired.

VIBRATION MEASUREMENTS WITH THE SOUND-LEVEL METER

By substituting a vibration pickup for the microphone, vibration measurements can be made with the TYPE 759-B Sound-Level Meter, provided the frequencies of components to be measured are above about 20 cycles per second. For this purpose, the use of the vibration pickup and control box described below is recommended.

VIBRATION PICKUP AND CONTROL BOX

The TYPE 759-P35 Pickup and TYPE 759-P36 Control Box have been designed for use with the TYPE 759-B Sound-Level Meter. To make vibration measurements with the sound-level meter it is merely necessary to replace the microphone by the control box and pickup.

The TYPE 759-P35 Vibration Pickup is an inertia-operated crystal device which generates a voltage proportional to the acceleration of the vibrating body. By means of integrating networks in the control box, voltages proportional to velocity and displacement can also be delivered to the sound-level meter. The desired response is selected by means of a three-point switch on the control box.

SPECIFICATIONS

Calibration: The db readings of the sound-level meter can be converted into absolute values of displacement, velocity, or acceleration by means of calibration figures supplied with each pickup and control box.

Range: The range of measurement of the pickup and control box when used with the TYPE 759-B Sound-Level Meter is approximately as follows:

R-m-s Double Amplitude — 30 micro-inches (minimum).

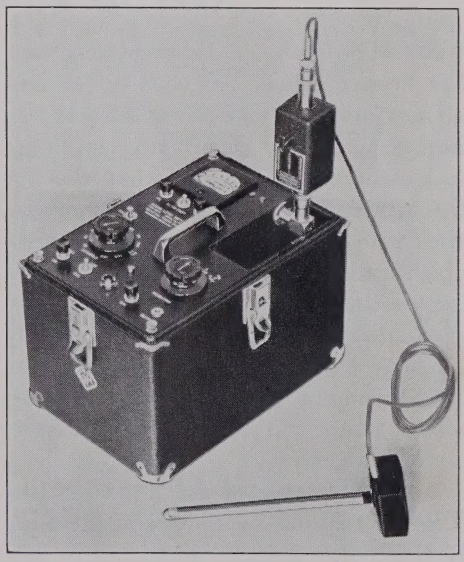
R-m-s Velocity — 1000 micro-inches per second (minimum). The upper limit of velocity and displacement measurements is dependent on the frequency and is determined by the maximum acceleration permissible before non-linearity occurs (10 g).

R-m-s Acceleration — 0.3 to 3900 in./sec./sec. (10 g)

Frequency Characteristic: The over-all response is approximately flat up to 1000 cycles.

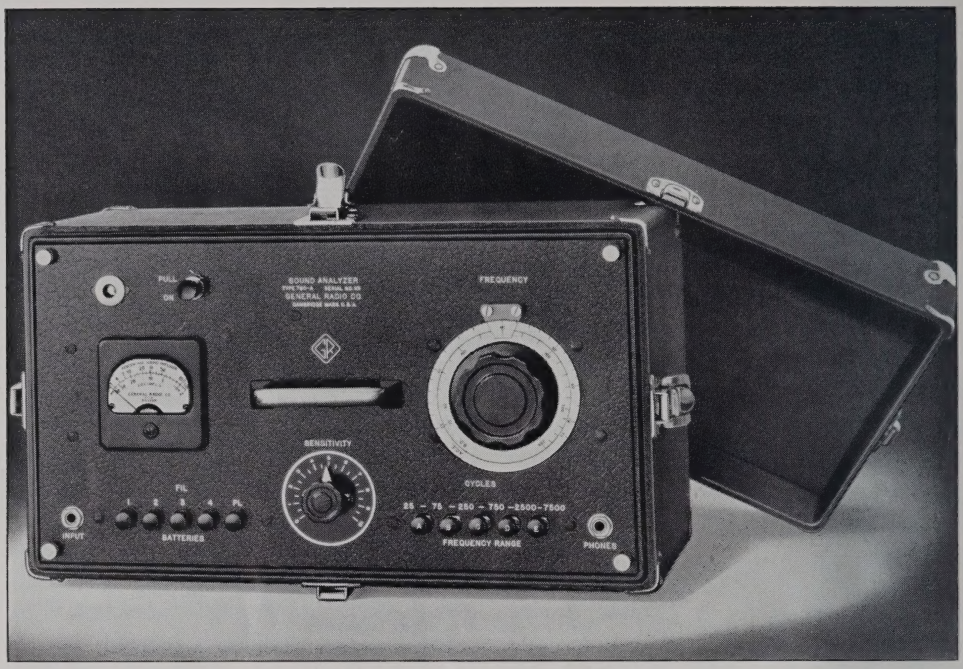
Mounting: Both control box and pickup are housed in metal containers, finished in black lacquer. The control box plugs into the sound-level meter, and the pickup in turn plugs into the control box. A flexible cable 7 feet long is supplied.

Net Weight: TYPE 759-P35 Vibration Pickup, 8 ounces (pickup only); pickup plus cable and tips, 1 pound; TYPE 759-P36 Control Box, 1 pound, 6 ounces.



The vibration pickup and control box plug into the sound-level meter in place of the microphone, as shown here.

Type		*Code Word*	*Price*
759-P35	Vibration Pickup	NOSEY	$40.00
759-P36	Control Box	NANNY	50.00



TYPE 760-B SOUND ANALYZER

Uses: The TYPE 760-B Sound Analyzer has been designed particularly for analyzing machinery noises or noise levels caused mainly by electrical or mechanical equipment. The fact that the selectivity curve widens proportionally as the frequency is increased makes it suitable for measuring noises caused by machines that do not run at absolutely constant speed. The instrument is particularly well adapted for analyzing the sound made by automobile and airplane motors and industrial or household equipment.

Although designed for use with the TYPE 759 Sound-Level Meter, the analyzer is not necessarily restricted to this application. It may be used in conjunction with any microphone and amplifier combination that provides sufficient output voltage.

As a general laboratory instrument the TYPE 760-B Sound Analyzer can be used as a harmonic analyzer to measure components down to 1% of the fundamental. It is very useful as a bridge-balancing indicator, since it can be tuned to the bridge frequency, thus eliminating errors caused by harmonics. The logarithmic indicating meter is of particular advantage in this application.

Another important use is the analysis of vibrations in conjunction with the TYPE 759-B Sound-Level Meter and vibration pickup.

Description: The TYPE 760-B Sound Analyzer consists of a selective amplifier, operating on the degeneration principle* and having a constant percentage band width, combined with a vacuum-tube voltmeter. The frequency to which the amplifier is tuned is indicated by a single dial and push-button multiplier.

The instrument was designed particularly for use with the TYPE 759 Sound-

*U. S. Patent No. 2,173,426.

Level Meter, and this combination provides an accurate and convenient means for measuring not only the actual level of sound, but also the relative amplitudes of the component frequencies.

Features: In the development of this analyzer, simplicity and convenience of operation were considered of primary importance. The frequency calibration is read directly on a large dial, which can be rotated continuously to cover the entire frequency range of the instrument with a minimum of effort. A push-button switch operates the multipliers, so that it is a simple matter to scan quickly the entire frequency range of the analyzer or to change the tuning between two remote points in the range.

A volume control is included to adjust the instrument for use at various input levels.

The selective circuits used in this analyzer contain only resistors and capacitors; no inductors are used. Because of this, external magnetic fields have no appreciable effect on the operation.

Since the instrument was designed as a companion to the TYPE 759 Sound-Level Meter, small size and low weight were considered extremely important, and the instrument is smaller and lighter than most of the analyzers which have been used for noise work in the past. The complete instrument is mounted in an airplane-luggage type of case.

SPECIFICATIONS

Frequency Range: Calibrated directly in cycles per second from 25 to 7500. This total range is covered in five complete turns of the tuning knob, the ranges on the various dial rotations being 25 to 75, 75 to 250, 250 to 750, 750 to 2500, and 2500 to 7500 cycles. A push-button switch allows immediate change of the main control to any of these ranges.

Frequency Calibration: The accuracy of frequency calibration is $\pm 1\frac{1}{2}\%$ of the frequency to which the dial is set or $\pm 1\frac{1}{2}$ cycles per second, whichever is the larger.

Voltage Range: The analyzer will give usable indications on input voltages ranging from 1 millivolt to 10 volts. The meter scale is calibrated for reading directly component tones down to 1% of the sound pressure (or voltage) of the fundamental or loudest component. Accordingly, to make full use of this feature, the input voltage at the loudest component or fundamental should be 0.1 volt or higher.

Input Impedance: The input impedance is between 20,000 and 30,000 ohms, depending upon the setting of the sensitivity control. A blocking condenser is in series with the input.

Frequency Response: The response is flat within ± 2 db over the entire range. At points where two ranges overlap, the sensitivity is the same on either range, within ± 1 db.

Band Width: The average selectivity is such that the relative attenuation is 3 db at 1% off the peak to which the analyzer is tuned.

Temperature and Humidity Effects: Under very severe conditions of temperature and humidity, slight shifts in calibration, sensitivity, and band width will occur.

Meter: The indicating meter is calibrated in two ranges, $+2$ to -30 db and -12 to -40 db. Auxiliary percentage scales of 0 to 120% and 0 to 24% are provided.

Telephones: A jack is provided on the panel for plugging in a pair of head telephones, in order to listen to the actual component of the sound to which the instrument is tuned. This is also useful when using the analyzer as a bridge-balance indicator.

Tubes: Three 1L4 and one 1U4 tubes are required. A neon pilot light (type NE-48) is also used. A complete set of tubes is supplied with the instrument.

Batteries: The batteries required are four Burgess No. 2FBP 1.5-volt batteries, or the equivalent, and three Burgess No. Z30NX 45-volt batteries, or the equivalent. A compartment is provided in the case of the analyzer for holding all batteries, and connections are automatically made to the batteries when the cover of this compartment is closed. A set of batteries is included in the price of the instrument.

Accessories Supplied: A shielded cable-and-plug assembly for connecting the analyzer to the sound-level meter.

Case: The analyzer is built into a shielded carrying case of airplane-luggage construction. In addition to the handle on the carrying case, a handle is provided on the panel of the instrument for convenience in moving the instrument about while it is in operation.

Dimensions: (Length) 18 x (width) 10 x (height) 11½ inches, over-all.

Net Weight: 34 pounds, with batteries; 27¼ pounds, without batteries.

Type		*Code Word*	*Price*
760-B	Sound Analyzer	ATTAR	$495.00
Set of Replacement Batteries for Above		ATTARADBAT	10.58

TYPE 762-B VIBRATION ANALYZER

Uses: The TYPE 762-B Vibration Analyzer makes possible the analysis of vibration phenomena having fundamental frequencies as low as 2.5 cycles per second. It is intended primarily for use with the TYPE 761-A Vibration Meter.

The frequency range covered (2.5 cycles to 750 cycles) includes practically all frequencies normally encountered in vibration studies, from the fundamental vibrations of ships and other large structures to the unbalance vibrations of high-speed centrifuges.

Description: This analyzer is similar in all essential characteristics of performance, construction, operation, and appearance to the TYPE 760-B Sound Analyzer except that the frequency has been lowered by a factor of 10 and provision has been made for operation with broad selectivity if desired. The latter arrangement is particularly useful in identifying components in the two lowest frequency ranges (2.5 to 25 cycles per second) and in making analyses involving components that vary slightly about a mean frequency.

SPECIFICATIONS

Frequency Range: 2.5 to 750 cycles, covered in five ranges as follows: 2.5 to 7.5, 7.5 to 25, 25 to 75, 75 to 250, 250 to 750.

Band Width: For the sharp selectivity position, the relative attenuation is approximately 30% (3 db) at a frequency differing by 1% from that to which the analyzer is tuned. For the broad selectivity position, the attenuation is 30% for a frequency difference of 5%. At one octave from the peak, the relative attenuations are 98% (35 db) and 90% (20 db), respectively.

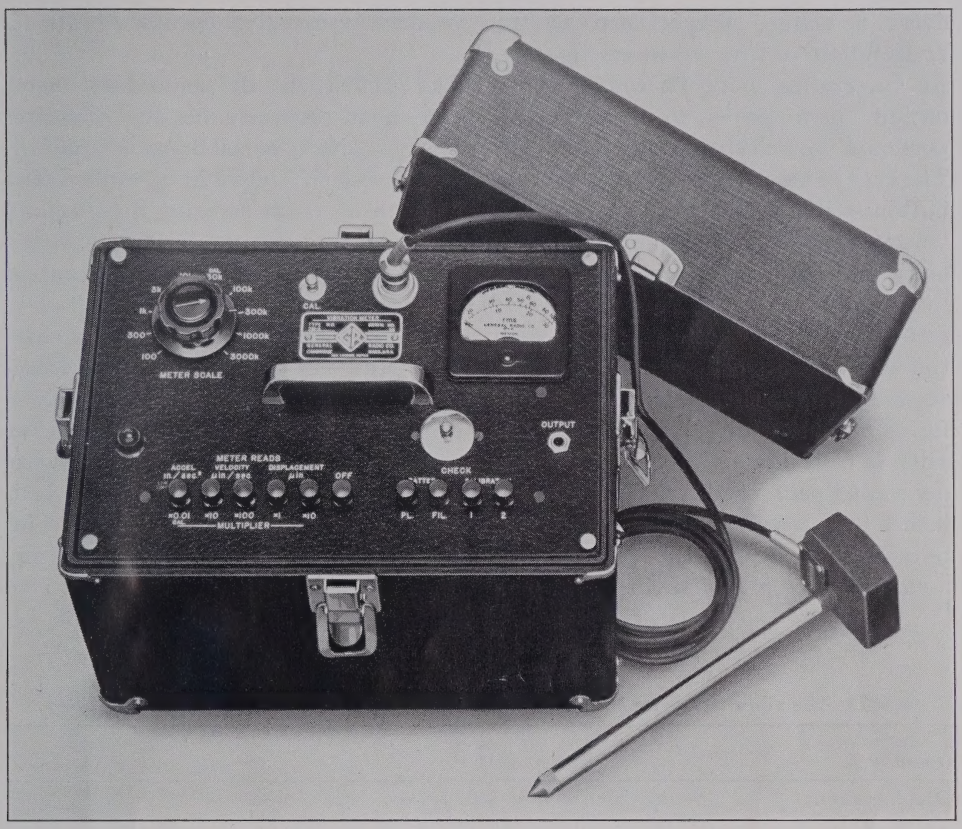
Frequency Calibration: The accuracy of frequency calibration of the sharp selectivity network is ±1½% or ±1½ cycles, whichever is the larger, over the three highest ranges (25 to 750 cycles); on the two lower ranges (2.5 to 25 cycles), the accuracy is ±5% or ±0.2 cycle, whichever is the larger. The frequency as determined with the broad selectivity network deviates on the average by less than ±2% from that determined with the sharp selectivity network.

Frequency Response: The response of the sharp selectivity network is flat within ±2 db over the entire range. At points where two ranges overlap, the sensitivity is the same on either range within ±1 db. The sensitivity of the broad selectivity network is the same as that of the sharp selectivity network to within ±2 db.

For other specifications see TYPE 760-B, page 49.

Type		*Code Word*	*Price*
762-B	Vibration Analyzer	AWARD	$540.00

TYPE 760-B Sound Analyzer and TYPE 762-B Vibration Analyzer are covered by U. S. Patent No. 2,173,426 and are also licensed under patents of the American Telephone and Telegraph Company.



TYPE 761-A VIBRATION METER

Uses: With the TYPE 761-A Vibration Meter measurements of the vibratory characteristics of machines and structures can be made quickly and easily. The excellent low-frequency response of this instrument makes possible the measurements of vibrations at frequencies as low as two cycles per second. This permits the study of the operation of belt drives and of the effectiveness of mountings designed to reduce vibrations in adjacent structures.

For the manufacturer of machinery and equipment, the TYPE 761-A Vibration Meter is extremely useful in research, design, and production testing. Maintenance engineers will find the instrument useful for checking the operating condition of bearings, gear trains, and other mechanisms. With this instrument excessive vibrations due to improper adjustment or design and to structural resonances may be located and measured.

When an analysis of the frequency spectrum of the vibration is desired, the TYPE 762-B Vibration Analyzer (see page 50) should be used, in conjunction with the vibration meter.

Description: The TYPE 761-A Vibration Meter consists essentially of a vibration pickup, an adjustable attenuator, an amplifier, and a direct-reading indicating meter. The pickup is of the inertia-operated crystal type which de-

livers a voltage proportional to the acceleration of the vibratory motion. An integrating network converts this output, when desired, to a voltage proportional to velocity or displacement. The type of response is selected by push-button switches. Thus the acceleration, velocity, and displacement of a vibrating body may be measured independently.

Calibrations are made in terms of r-m-s values. The basic units in which the instrument is calibrated, inches and seconds, are the simplest and least confusing of those commonly used. Acceleration is read directly in terms of inches per second per second, velocity in micro-inches per second, and displacement in micro-inches. Calibrations are made on a motor-driven precision vibrator, which produces essentially sinusoidal vibrations.

Features: Like the sound-level meter and sound analyzer, this new vibration meter is small, portable, self-contained, and extremely simple in operation. The instrument reads directly the absolute value of the quantity under measurement so that no reference to calibration figures is necessary.

The inclusion of three response characteristics—namely, acceleration, velocity, and displacement—and the extension of the range down to 2 cycles per second with substantially flat response characteristics provide a degree of flexibility hitherto unapproached in commercially available vibration-measuring apparatus.

SPECIFICATIONS

RANGES: The vibration meter is direct-reading in the units shown in the range table below.

Vibration Quantity	*Range*
Displacement	16 micro-inches to 30 inches, rms.
Velocity	160 micro-inches per second to 300 inches per second, rms.
Acceleration	0.160 inch per second per second to 3900 inches per second per second, rms.

RESPONSE CHARACTERISTICS: The response follows theoretical curves of the quantity measured, vs. frequency within the following tolerances.

Quantity	*Range*	*Tolerance*	*Frequency Range*
Acceleration	0.160 in./sec/sec to 3900 in./sec/sec	±10%	4 to 500 cps. Down 25% at 2 cps.
Velocity	1600 μin./sec to 300 in./sec	±10%	5 to 500 cps. Down 40% at 2 cps.
Velocity	Below 1600 μin./sec	±15%	20 to 500 cps. Down 25% at 10 cps.
Displacement	160 μin. to 30 in.	±10%	10 to 500 cps. Down 50% at 2 cps.
Displacement	Below 160 μin.	±15%	20 to 500 cps. Down 25% at 10 cps.

Above 500 cps the error increases and may reach ±30% at 1000 cps. This is caused by the differences in response of individual pickups near resonance.

Pickup Unit: The vibration pickup is of the inertia-operated crystal type, housed in a cast aluminum container. The maximum vibration acceleration which can be impressed upon the pickup before non-linearity occurs is 10 g or 3900 inches per second per second. Point and ball tips and an 8-inch extension rod are supplied.

Meter: The indicating meter has a scale which reads directly in the quantity being measured—r-m-s micro-inches for displacement, r-m-s micro-inches per second for velocity, and r-m-s inches per second per second for acceleration.

Attenuators: A 10-step attenuator is provided which changes the meter scale calibration over a range of 30,000 to 1. Additional multipliers are provided which indicate the correct units of measurement and multiplying factors for each response characteristic.

Calibration: A calibrating circuit is provided in the instrument which, by connection to any a-c power line, makes it possible to check the overall calibration of the vibration meter, excluding the vibration pickup.

SPECIFICATIONS

Input: 2.0 volts, 400 cycles; total harmonics must not exceed 5%.

Output: When in position on the Sound-Level Meter, the calibrator produces a sound pressure of 85 ±1 db (above a reference level of 0.0002 microbars, i.e., 0.0002 dynes per square centimeter) at the microphone diaphragm.

Terminals: Input terminals are TYPE 938-W Binding Posts.

Accessories Required: 400-cycle oscillator, output control, and vacuum-tube voltmeter. TYPE 813-B Audio Oscillator, TYPE 301-A (500-ohm) Potentiometer, and TYPE 1803-A Vacuum-Tube Voltmeter or an accurate rectifier-type voltmeter are satisfactory.

Dimensions: (Length) 4½ x (diameter) 2½ inches, overall.

Net Weight: 10½ ounces.

Type		*Code Word*	*Price*
1552-A	**Sound-Level Calibrator**	NATTY	$ 45.00
813-B	**Audio Oscillator** — 400 cycles	AMUSE	85.00
301-A	**Potentiometer** — 500 ohms	RIVAL	2.25
1803-A	**Vacuum-Tube Voltmeter**	ABOOM	155.00

Sound Level Meter
Type 759

Telephones: A jack is provided on the panel for plugging in a pair of head telephones in order to listen to the vibrations being measured, for connecting the TYPE 762-B Vibration Analyzer, or for connecting a cathode-ray oscillograph. Practically any load impedance can be impressed across this output telephone jack without affecting the reading of the meter.

Tubes: Three 1N5-GT/G tubes and one 1D8-GT tube are required. A complete set of tubes is supplied.

Battery: A single battery unit, BA48, Burgess 6TA60, which supplies the necessary plate and filament voltages, is included.

Accessories Supplied: Power cable for calibration check, spare pilot lamp, and plug for output jack.

Case: The unit is built into a shielded carrying case of airplane-luggage construction, covered with durable black waterproof material, and equipped with chromium-plated corners, clasps, etc.

Dimensions: The over-all dimensions are approximately: (height) 12½ inches x (length) 13½ inches x (width) 9½ inches.

Weight: 22¾ pounds with battery; 14¾ pounds without battery.

Type		*Code Word*	*Price*
761-A	**Vibration Meter**	VIRUS	**$490.00**
Replacement Battery for Above		VIRUSADBAT	**5.50**

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TYPE 1552-A SOUND-LEVEL CALIBRATOR

Uses: The Sound-Level Calibrator provides a means of making an over-all acoustic check of the Sound-Level Meter calibration, including the microphone. In conjunction with the internal calibration check on electrical circuits, which is provided in the Sound-Level Meter, the Sound-Level Calibrator makes it possible to detect and to evaluate any long-period change in over-all sensitivity and to locate it either in the microphone or the electrical circuits. Such a check is invaluable where a series of measurements are to be taken over a long period, or where several meters are to be intercompared.

Description: The calibrator consists of a small, stabilized, and rugged loudspeaker, mounted in an enclosure that fits over the microphone of the Sound-Level Meter. The enclosure is so designed that the speaker is always located at the correct distance from the microphone diaphragm. A standard 400-cycle voltage is required to operate the calibrator (see specifications following).